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EDDY CURRENT

Volume II - Equipment, Methods and Applications

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INTRODUCTION

This handbook is one of a series on nondestructive testing, and is the second in a set of two volumes presented on the subject of Eddy Current ~~Testing~~.

The identification and inspection of base metals and metal alloys has become an increasingly important factor in the production and fabrication of metal products. Special alloys, differing only slightly in composition and not at all in appearance, can be identified, and inspected for discontinuities by the eddy current test method.

Applications of some of the various eddy current testing methods are presented in this volume. Some discussion of the different coils that are used and their physical and electrical design should help the reader get a feel for the electromagnetic testing systems. The indications, displays and charts that are used for testing purposes as well as some of the requirements for acceptable test standards are also presented.

THE EDDY CURRENT TESTING PROGRAMMED INSTRUCTION series (two volumes) will provide some of the background material necessary to take you one step closer to your goals in the area of nondestructive testing. The two volumes should be read in sequence because much of the material in Volume II is based on facts learned in Volume I.

INSTRUCTIONS

The pages in this book should not be read consecutively as in a conventional book. You will be guided through the book as you read. For example, after reading page 3-12, you may find an instruction similar to one of the following at the bottom of the page --

- Turn to the next page
- Turn to page 3-15
- Return to page 3-10

On many pages you will be faced with a choice. For instance, you may find a statement or question at the bottom of the page together with two or more possible answers. Each answer will indicate a page number. You should choose the answer you think is correct and turn to the indicated page. That page will contain further instructions.

As you progress through the book, ignore the back of each page. THEY ARE PRINTED UPSIDE DOWN. You will be instructed when to turn the book around and read the upside-down printed pages.

As you will soon see, it's very simple -- just follow instructions.

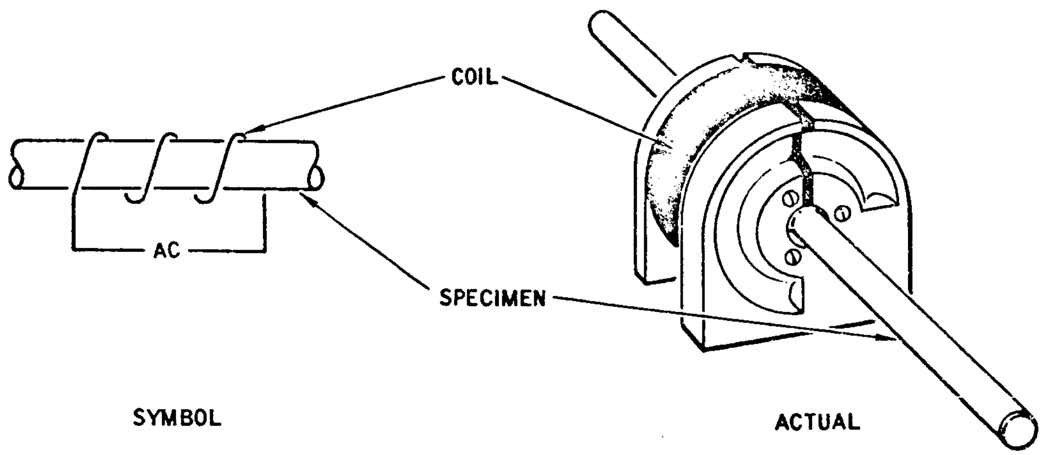
Turn to the next page.

In eddy current testing we find that there are three commonly used test coils:

- Encircling coil
- Inside coil
- Surface coil (Probe)

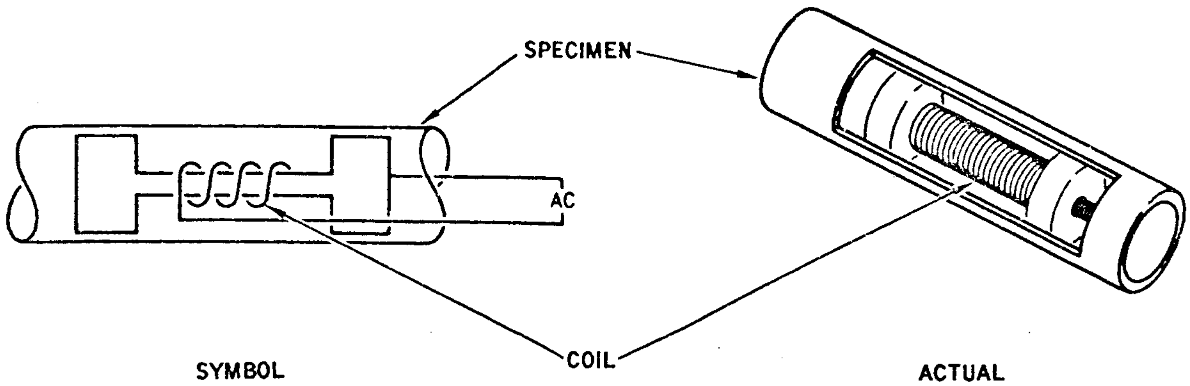
Each of these is a coil of wire, wound such that it can be used for a specific application.

The following illustrations will give you a general idea as to their appearance:

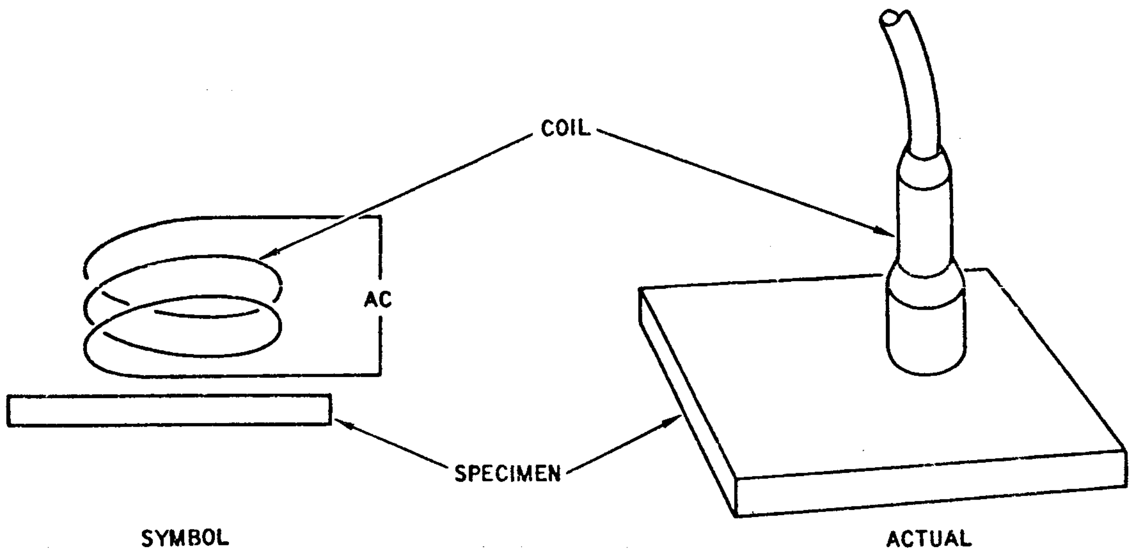


ENCIRCLING COIL

Turn to the next page.



INSIDE COIL



SURFACE COIL

Of the three coils, which would be best for testing a one-inch diameter metal bar?

Encircling coil .... Page 1-4

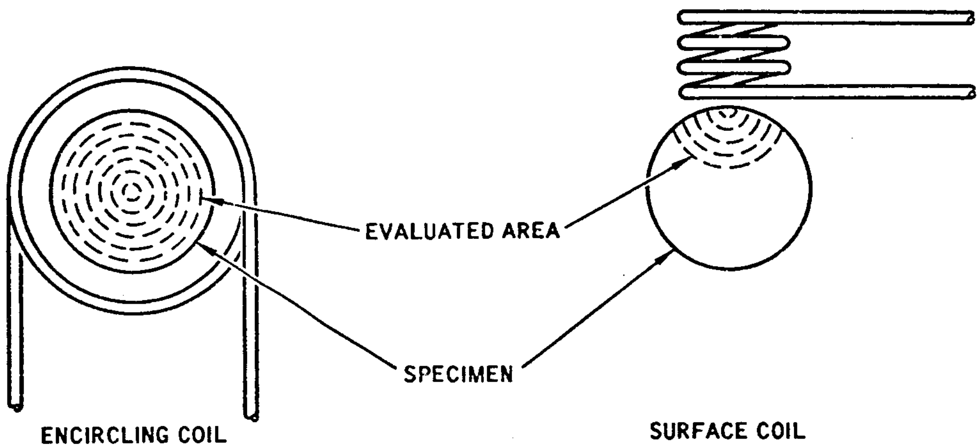
Inside coil .... Page 1-5

Surface coil .... Page 1-3

The surface coil is not a good choice. Even though it could be used, it would not do the job as well as the encircling coil. The encircling coil evaluates the entire circumference of the bar while the surface coil would only evaluate the immediate area under its probe.

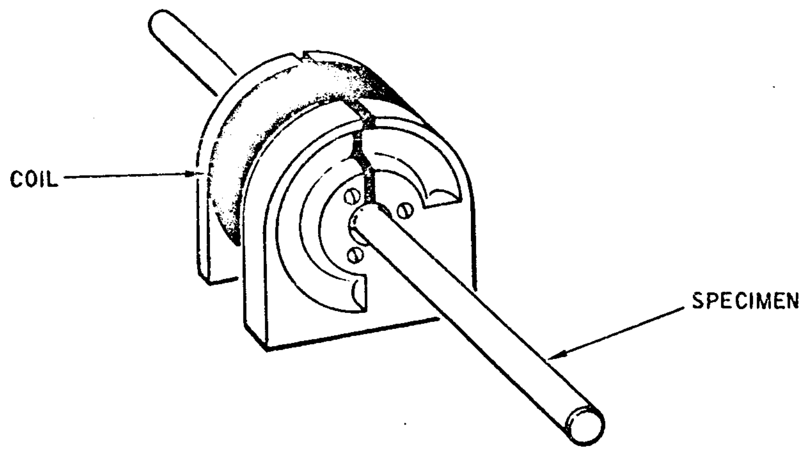
The correct choice should have been the encircling coil.

The illustration below shows an end view of the specimen and the eddy current evaluation in each instance:



Turn to page 1-4.

Good, you made the correct choice. When testing a small metal bar such as the one described, the use of the encircling coil would be the best choice. It is quite obvious that the inside coil could not be used and it would be quite impractical to use the surface probe as you will see shortly.



The encircling coil allows the specimen to pass continuously through the center of the coil. With specimens of continuous stock, speeds up to one thousand feet per minute are possible. With the encircling coil, the entire circumference of the specimen is evaluated at one time. This is a very important feature of the encircling coil, a feature that is not present with the surface coil.

The ability to evaluate the entire circumference of the specimen (when the specimen is a bar or tube) lies with:

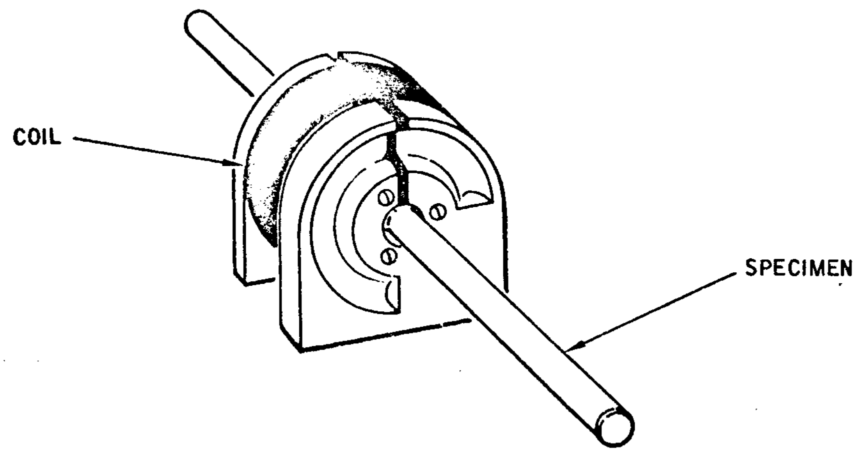
Encircling and surface type coils . . . . Turn to page 1-6

Surface and inside type coils . . . . Turn to page 1-8

Inside and encircling type coils . . . . Turn to page 1-7

From page 1-2

Sorry, but you made the wrong choice. The inside coil could not be used to evaluate a solid bar specimen. The inside coil is used inside tubes or where it is necessary to check a hollow specimen. Since the bar is solid, it becomes necessary to check it from the outside. The correct choice is the encircling coil because the bar can be inserted inside of the coil.

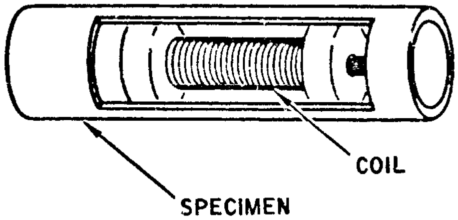


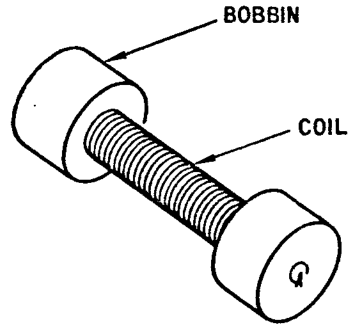
Turn to page 1-4.

You made an incorrect choice. If you recall, a surface coil cannot evaluate the entire circumference of a bar or tube. A surface coil will evaluate only the portion of the specimen directly under the coil. The "encircling" part of your answer was correct since the encircling coil and the inside coil can evaluate a circumference.

Return to page 1-4 and make another selection.

Well done! You made the correct selection. You recognized that the inside coil will evaluate an entire circumference the same as an encircling coil. The difference of course is that the inside coil is used to test the inside of large tubing where it would be impractical to use an encircling coil or in cases where the wall thickness requires that both inside and outside surfaces be tested.





As you can see from the above illustration, the coil is wound on a bobbin so constructed as to keep the coil centered inside the tube. This is an important requirement as you know from your study of Volume I. The distance between the coil and the specimen will determine the test effectiveness. There is a disadvantage of encircling and inside coils however; since these coils evaluate the entire circumference at one time, they do not identify the exact location of a discontinuity. That is, the discontinuity is detected but its exact point within the area tested is not shown.

Visualize that you have a hollow tube with a discontinuity . The general area of the discontinuity was determined when checking with an encircling coil. Which of the below listed coils could more accurately pinpoint the exact location of the discontinuity?

Encircling coil . . . . Turn to page 1-9

Surface coil . . . . Turn to page 1-11

Inside coil . . . . Turn to page 1-10

From page 1-4

You made an incorrect choice. If you recall, a surface coil cannot evaluate the entire circumference of a bar or tube. A surface coil will evaluate only the portion of the specimen directly under the coil. The "inside" part of your answer was correct since the inside coil and the encircling coil can evaluate a circumference.

Return to page 1-4 and make another selection.

From page 1-7

Ooops! Wrong choice, remember an encircling coil and an inside coil test the entire circumference. They indicate that there is a discontinuity somewhere in the circumference, but do not give the exact location. This can best be done with a surface coil. The surface coil, in scanning the specimen, will only detect the discontinuity when it is directly over it. In so doing, it will pinpoint the discontinuity to an exact spot.

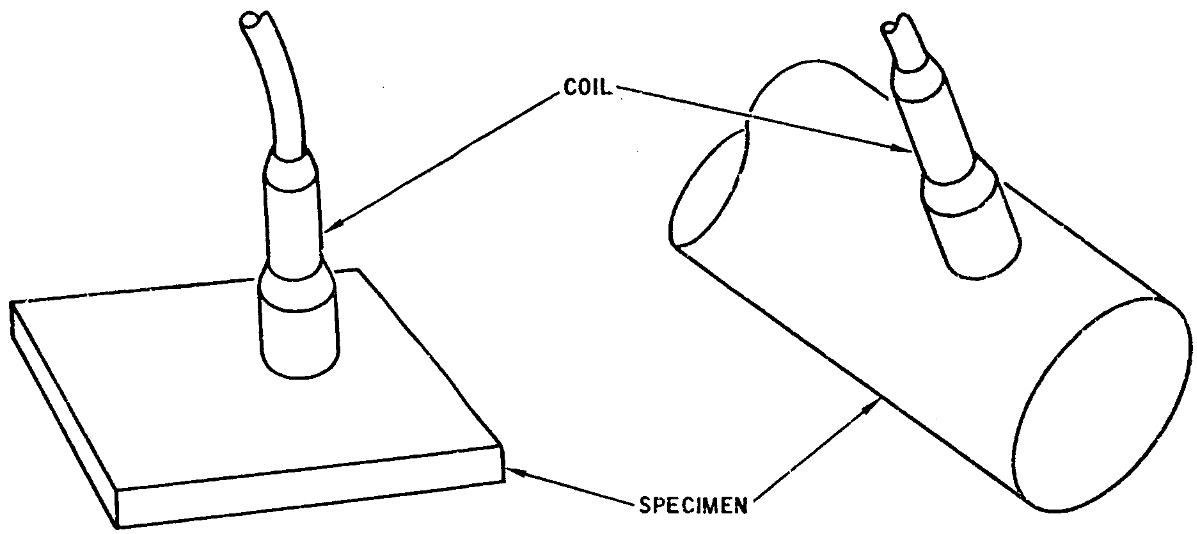
Turn to page 1-11.

From page 1-7

Ooops! Wrong choice, remember an inside coil and an encircling coil test the entire circumference. They indicate that there is a discontinuity somewhere in the circumference, but do not give the exact location. This can best be done with a surface coil. The surface coil, in scanning the specimen, will only detect the discontinuity when it is directly over it. In so doing, it will pinpoint the discontinuity to an exact spot.

Turn to page 1-11.

Right again! The surface coil is the correct coil to use for exact location of the discontinuity. The surface coil, also called the probe coil is normally housed in a holder with the coil wound around a core that extends through the bottom of the housing. The surface or probe coil can be operated by hand or automatically made to scan the surface of the specimen.



Is the distance between the surface coil and the specimen an important consideration?

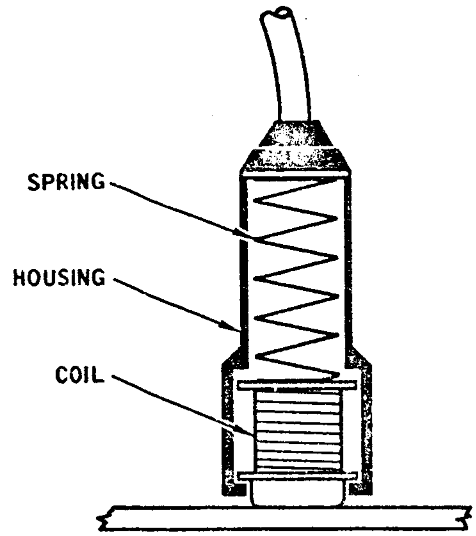
Yes . . . . Turn to page 1-13

No . . . . Turn to page 1-12

You must have forgotten the things that you learned in Volume I. Do you remember lift-off? The distance between the coil and the specimen is a critical factor when using a surface coil. As we learned earlier, a change in output indication can be caused by a variation in the distance between the probe and the specimen.

Turn to page 1-13.

Your memory serves you well. This distance, called lift-off, between the probe and the specimen is a very critical factor and thus must be controlled as much as possible. By proper design of the probe and indicating equipment it is possible to eliminate some of the lift-off effect where it presents an unwanted indication.



In some surface coil probes the coil extension is spring-mounted such that, independent of pressure applied by the operator, a constant spring pressure is applied to the coil and holds it firmly against the specimen.

Does the pressure applied by the coil on the specimen have any effect on the output indication?

Yes . . . . Turn to page 1-14

No . . . . Turn to page 1-15

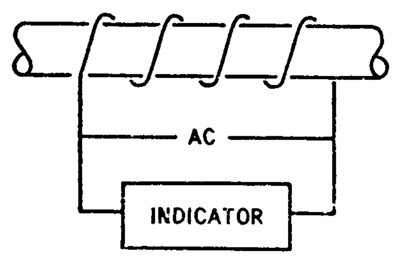
That's correct: You see that changes in pressure between the coil and the specimen can create variations in the output indication. Another similar method of eliminating undesirable variations in the output indications is to recess the coil into the probe housing so that, with a constant "lift-off" distance between the coil and the specimen, minor variations in the specimen will not be detected.

The three coils described,

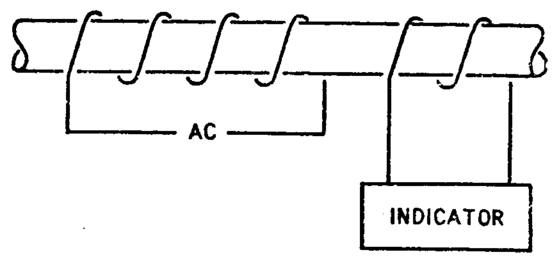
- encircling
- inside
- surface

may also be classified in single or double coil arrangements.

Using the encircling coil as an example, we illustrate the single coil type with the output indicator connected as shown. With this arrangement the indicator is connected directly to the alternating current (ac) source.



With the double coil type, we illustrate two separate coils: one (primary) connected to the ac source, and the other (secondary) is connected to the indicator.



We have learned that there are three types of coils: (1) encircling, (2) inside, and (3) surface. Can the double coil arrangement be used on . . .

encircling coils only . . . . Turn to page 1-16

encircling, inside, and surface coils . . . . Turn to page 1-17

No, that is not the correct choice. Ofttimes the probe is very sensitive to changes in pressure on the specimen. This is one of the primary reasons why the coil is placed under spring pressure. This places a constant unvarying pressure between the coil and the specimen. If the probe is of a sensitive type (that is, one that measures very small discontinuities) a change in pressure may change the lift-off effect enough to give a false output indication.

The correct answer to the question "Does the pressure applied by the coil on the specimen have any effect on the output indication?" is Yes.

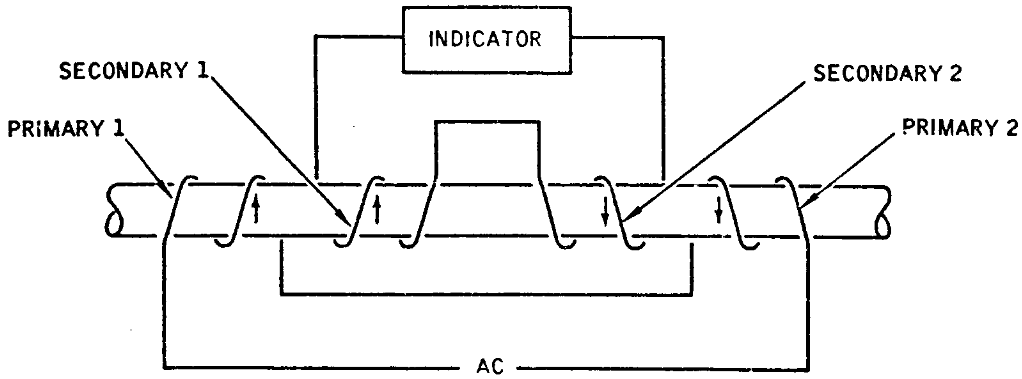
Turn to page 1-14.

Nope, wrong choice. As we stated on page 1-14, all three coils (encircling, inside, and surface) may be classified in either the single or double coil arrangements. A clearer illustration is possible when using the encircling coil to show the different applications. Hope we didn't foul you up.

Turn to page 1-17.

You are so right! The double coil arrangement can be used on all three; encircling coils, inside coils, and surface coils.

Let's try another step now in our study of coils. A close look at the illustration below will reveal that we still have only two coils but they are wound such that they are in opposition to each other.



As you can see, "PRIMARY 1" winding is wound opposite to "PRIMARY 2". Thus the electrical fields oppose each other. The same situation exists with "SECONDARY 1" and "SECONDARY 2".

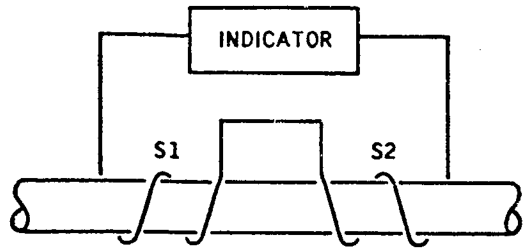
This seems rather strange, don't you think, that they would be wound such that they are in opposition.

Do you suppose that under such circumstances that these coils would . .

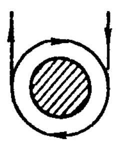
cancel each other . . . . Turn to page 1-19

double each other . . . . Turn to page 1-18

Slow down there, if they oppose each other, that means they will cancel or nullify each other. Let's have a look at the secondary coil:



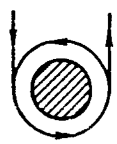
If the current in one coil (S1) is going around the specimen in a clockwise direction,



it will set up a magnetic field.

S1

Now, if we reverse the winding in the other coil (S2) such that the current will flow counterclockwise,



S2

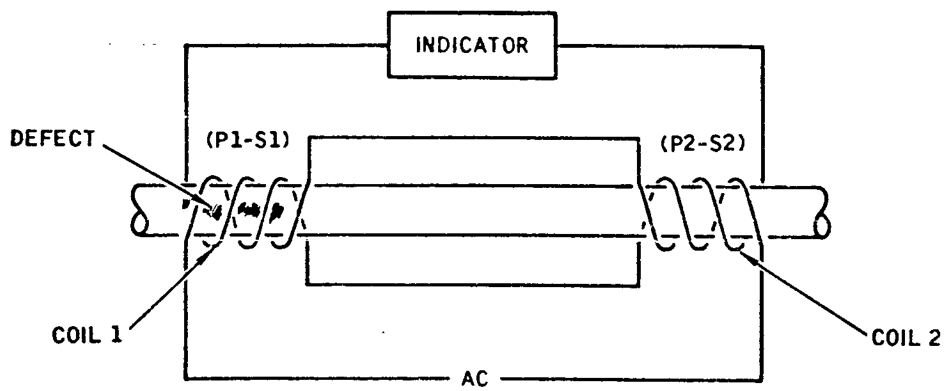
then the magnetic fields of S1 and S2 will oppose each other and cancel out.

Return to page 1-17 and make another selection.

From page 1-17

Well done! With primary 1 - primary 2 in opposition, and secondary 1 - secondary 2 in opposition, the coils cancel each other. That is, their fields being equally strong in both directions, one will nullify the other. So, when a specimen with no dis- discontinuities is placed within the coils, there will be no indication.

Actually as seen in the next illustration, primary 1 (P1) and secondary 1 (S1) are wound together, primary 2 (P2) and secondary 2 (S2) likewise. The reason for this is: P1-S1 form a coil and inspect one part of the specimen and P2-S2 form a coil and inspect a different part of the specimen. We now have what is referred to as <u>differential coils</u>.



If, in a situation like that illustrated above, there was a discontinuity in the specimen under coil 1 (P1-S1) while the specimen under coil 2 (P2-S2) was discontinuity free — do you think there would be an output indication on the indicator?

Yes . . . . Turn to page 1-21

No . . . . Turn to page 1-20

Maybe we sprung that on you a little too soon. Actually this is what happens when we use the differential coil arrangement. When the specimen inside of one of the coils is different (contains discontinuities) from the specimen inside of the other coil there will be an output indication because the two coils no longer balance (equally cancel) each other.

Turn to page 1-21.

From page 1-19

Oh, how right you are! That's good thinking. There will be an output indication with a discontinuity under one coil. Here is how it works. Assume that the differential coils are set up with a bar or tube specimen moving through them. With no discontinuities under either of the coils, the induced magnetic fields will balance or cancel each other. Now, when a discontinuity comes along it passes through one of the coils. This changes the magnetic field about the coil and the balance no longer exists, there is a difference between the two coils and they no longer cancel each other. Thus, an output indication will appear on the indicator. Hence, the term differential. The two coils, actually sense a difference and give a signal that a discontinuity has been observed.

Since we are comparing two separate places on the same specimen, would it be wrong to call this method the self-comparison method?

Yes . . . . Turn to page 1-22

No . . . . Turn to page 1-23

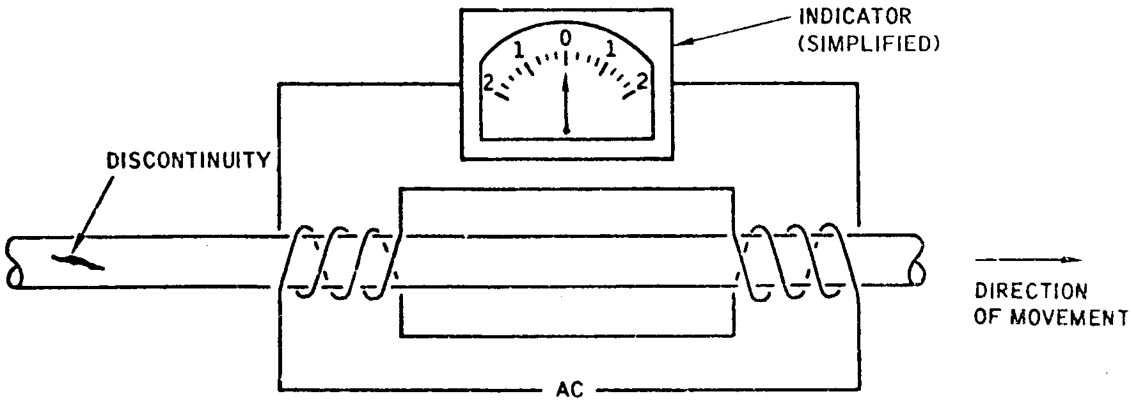
From page 1-21

Yes, is the wrong answer. Since we are comparing one place on a specimen with another place on the same specimen, we can and do call this the self-comparison method - we are actually comparing the specimen with itself.

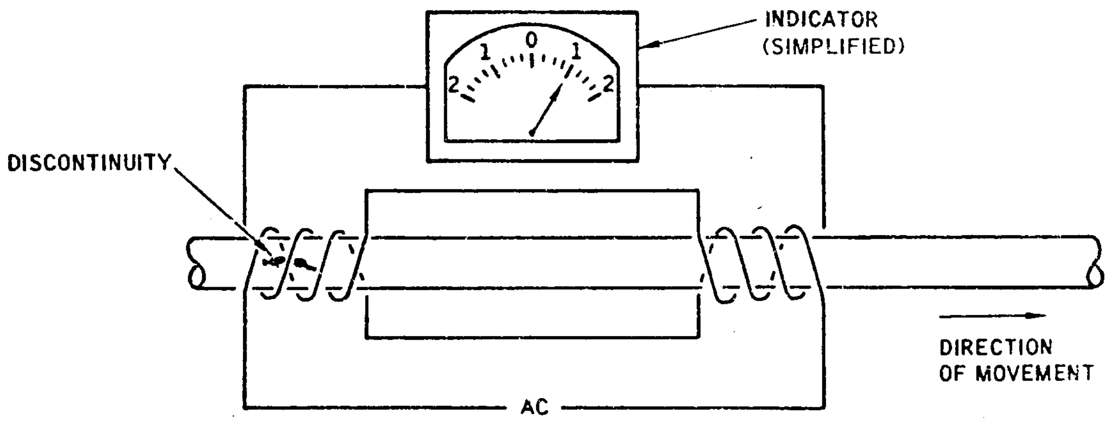
For further information turn to page 1-23.

Very good. No, is the correct answer. The method described is called the self-comparison method. As you can see, the two coils are testing different places on the specimen. In so doing, they actually compare the two places and only when a difference occurs will there be an indication. You see, one coil will nearly always be inspecting an acceptable part of the specimen. Only when a discontinuity occurs will the other coil detect it. Let's have a look:

In the first illustration, the specimen under both coils is acceptable (discontinuity free). With no difference detected between the coils there is of course no indication.



However, when the discontinuity passes under one of the coils a comparison is made with the acceptable portion and a difference is detected. Now of course we will have an indication.



Another comparison type - differential coil arrangement - using a separate, discontinuity free standard, would be called:

External reference . . . . Turn to page 1-25

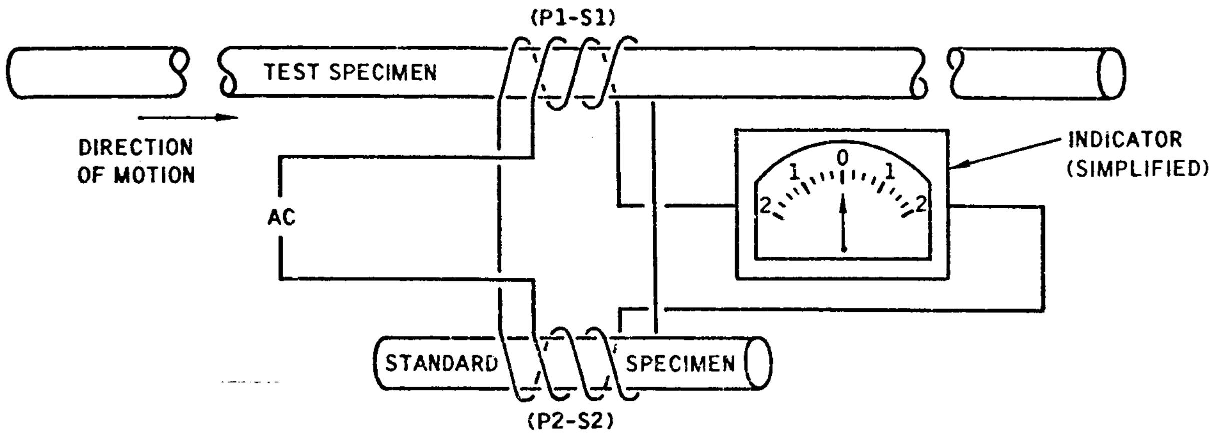
Self comparison . . . . Turn to page 1-24

From page 1-23

Now, you should know better than that. With a separate, discontinuity free standard it would not be self comparison. You may recall that self comparison is where the coil is testing two places on the same specimen. Now we suggested using a separate test specimen and so we have an external reference.

Return to page 1-23 and try again.

A good choice! If we use a separate test standard, we will have an external reference. We can do this with a coil arrangement exactly the same as the self-comparison coil only set up slightly different. A differential coil arrangement can be set up with a carefully chosen, discontinuity free test specimen held stationary in one coil while the specimen being tested is moving through the other coil.



Here, as you can see, coil P2-S2 and the discontinuity free specimen are set up as a standard. As the specimen being examined (test specimen) passes through coil P1-S1, a comparison is made between the two. No indication is observed of course unless a discontunluty appears in the test specimen being examined. If a discontinuity passes through coil P1-S1, it causes a change in the coil impedence and thus an indication is exhibited.

A change in the specimen size or dimension will not affect the coil impedence or give an indication.

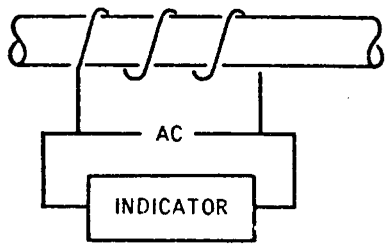
True . . . . Turn to page 1-27

False . . . . Turn to page 1-26

From page 1-25

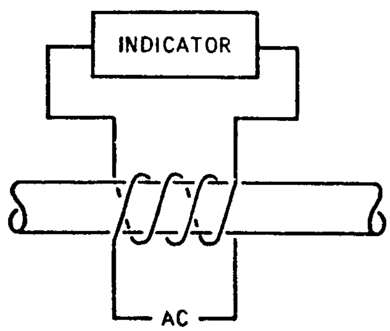
That's right! A change in size or dimension will change the fill-factor ratio of coil diameter to specimen diameter such that an indication is exhibited. With this concept in mind you can see how dimensional changes can be detected by eddy current methods.

There are various arrangements of the three major types of coils that are divided into different classes. Some of these we discussed earlier. As you recall from the previous pages, we started with a single coil around the specimen.



This single coil will inspect only the area under the coil and does not compare it with itself (self-comparison) or with a standard (external reference). Because it tests the specimen without a comparison, we call it "absolute".

In the illustration below, the coil system is:



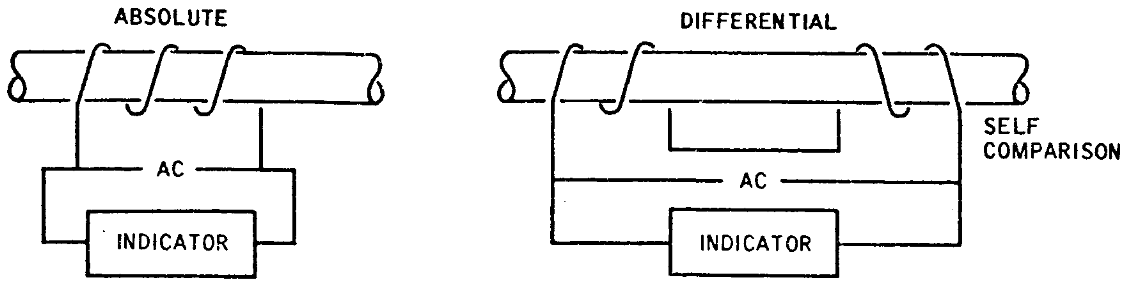
absolute . . . . Turn to page 1-28

differential . . . . Turn to page 1-29

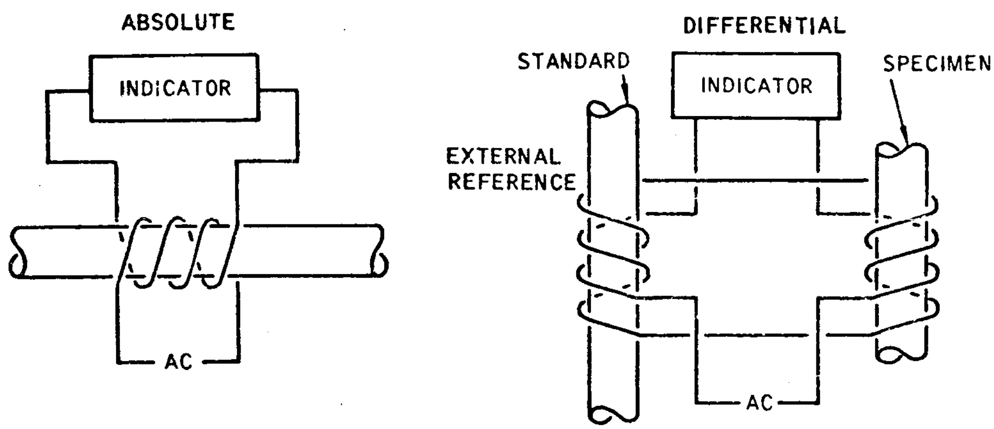
That will never do, you learned in Volume I that a change in dimension in the test specimen would change the impedence in the coil - especially where fill-factor is involved. If you recall, the <u>fill-factor</u> is a <u>ratio</u> of the <u>coil diameter</u> and the <u>specimen diameter</u>. A change in the specimen size will change this ratio and an indication will be received.

Turn to page 1-26.

Very good! This is a little confusing but you made the correct choice. You recognized that even though there were two coils, they were testing only the specimen that passed through them. They made no self comparison or external reference comparison. The illustrations below may help.



SINGLE COIL (ENCIRCLING)



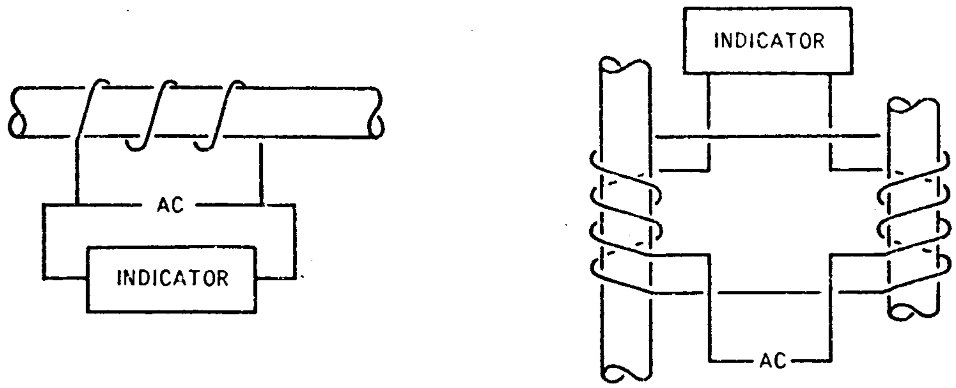
DOUBLE COIL (ENCIRCLING)

Do you think that single and double coil arrangements for testing could be applied to specimens other than tubes or cylinders?

Yes . . . . Turn to page 1-30

No . . . . Turn to page 1-31

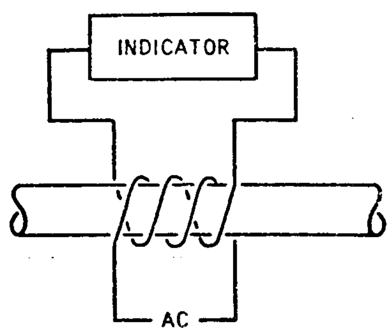
Wrong choice! You forgot that the differential coil makes a comparison, either self comparison or external reference. You see, the differential coil arrangement measures the difference between the specimen under test and the specimen used for comparison.



SELF COMPARISON EXTERNAL REFERENCE

DIFFERENTIAL COIL

The absolute coil system simply gives an indication of what passes through its coil without any comparison.



ABSOLUTE COIL

Turn to page 1-28.

Good thinking! Eddy current tests have many different applications and many different types of test may be conducted. In fact we have a separate chapter (Chapter 3) designed especially to show the various applications and uses of eddy current testing.

The same principle of absolute and differential coil systems apply to the other two types of coil (internal and surface) each having a specific and useful purpose.

Turn to page 1-32 for a short review.

From page 1-28

We didn't mean to mislead you by making all of the illustrations using tubes or cylinders for example specimens. In actuality, specimens of many different shapes and sizes are tested with eddy current. Using the methods described previously we can test plates, thin sheets, inside parts, thickness, and many other objects. We will discuss these others in Chapter 3.

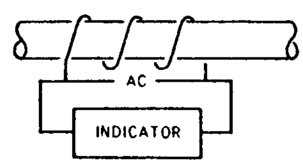
Now turn to page 1-30.

From page 1-31

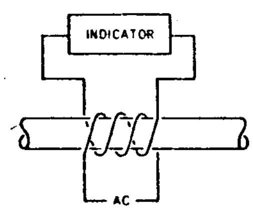
SUMMARY OF CHAPTER 1

TEST COILS

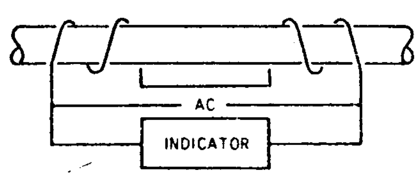
1. The three most commonly used test coils are:
   a. Encircling coil
   b. Inside coil
   c. Surface coil (probe)
2. The encircling coil is used on rods, tubes, cylinders, or wire.
3. The inside coil is used on tubes or pieces that have the inside accessible for coil insertion.
4. The surface coil (probe) is used on plates, sheets, or irregular shaped articles.
5. With the encircling and inside coils, the entire circumference of the specimen is evaluated at one time.
6. The surface coil has the advantage of being able to better pinpoint the exact location of the discontinuity.
7. The distance, called lift-off, between the coil and the specimen is a very critical factor and thus must be controlled as much as possible.
8. This is a single coil - absolute. . .



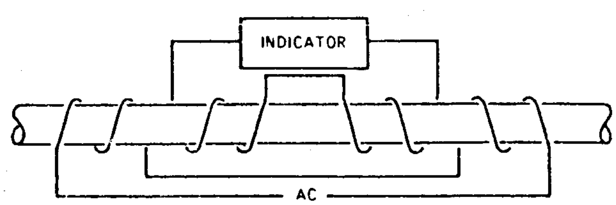
9. This is a double coil - absolute. . .



10. This is a single coil - differential. . . (Self-comparison)



11. This is a double coil - differential. . . (Self-comparison)



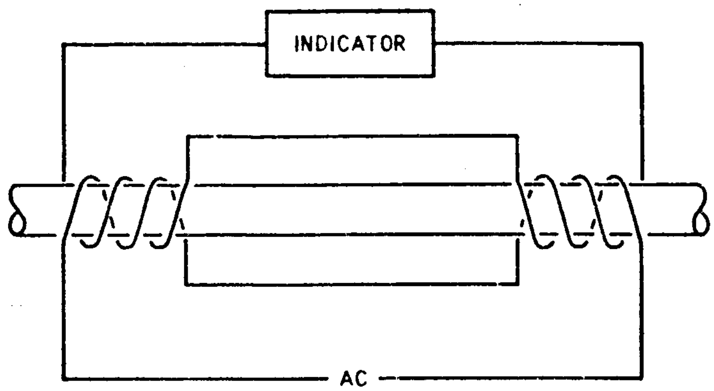
● [redacted])

From page 1-32

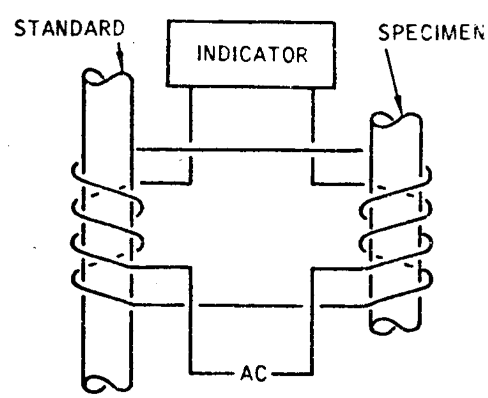
SUMMARY OF CHAPTER 1 (Cont)

12. In the differential coil arrangement, the coils oppose each other and give a zero output when no discontinuity exists.

13. This is a self-comparison type coil. . .
(Double coil - differential)



14. This is an external comparison type.
It uses a separate discontinuity free standard for comparison. . .
(Double coil - differential)



15. By various arrangements of electrical circuits, surface coils and inside coils will also use these different coil systems.

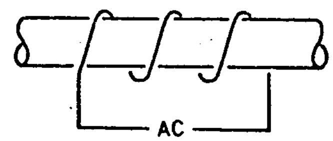
[redacted]

From page 1-33

1. The next few pages are different from the ones which you have been reading. There are _____ arrows on this page. (Write in the correct number of arrows.) Do not read the frames below. FOLLOW THE ARROW and turn to the TOP of the next page. There you will find the correct word for the blank line above.

5. Inside coil

6. Identify this type of coil:



Answer ______________________

11. Surface

12. The distance between the surface coil and the specimen is called

________ - __________.

17. self-comparison

18. The use of a separate specimen established as a standard for a specific test is called the:

. . . self-comparison method.

. . . external reference method.

This is the answer to the blank in Frame number 1.

1. four

Frame 2 is next

2. These sections will provide a review of the material you have covered to this point. There will be one or more blanks in each f__________.

Turn to the next page.
Follow the arrow

6. encircling coil

7. Which of the three basic coils would be used when checking for discontinuities in metal plates.

Answer ____________________

12. lift-off

13. The double coil arrangement can be used on:

1. One type of coil? 2. Two types of coils? 3. Three types of coils?

18. external reference method

19. Will a change in specimen size generally give an indication?

Yes ______ No ______

From page 1-35

2. frame

3. By following the arrows or instructions you will be directed to the section which follows in sequence. Each section presents information and requires the filling in of ___________.

7. Surface

8. Which of the three basic coils would probably not be used for checking tubing or cylinders.

   Answer ____________________

13. All three types of coils.

14. In the double coil arrangement the indicator is not connected to the ac source.

    True ______ False ______

19. Yes

20. When a comparison is not made with a differential coil it is termed:

    a. Absolute b. External reference

From page 1-36

3. blanks (or spaces or words)

4. List the three basic coil types.

   1. ________________ 2. ________________ 3. ________________

8. Surface coil

9. Will a surface probe evaluate the entire circumference of a specimen at one time?

   Yes ______ No ______

14. True

15. With a differential coil arrangement, are the coils wound in opposition to themselves?

   Yes ______ No ______

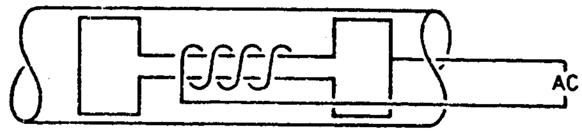
20. Absolute

21. Can the absolute test equipment be wound with both single and double coil arrangement?

   Yes ______ No ______

4. Encircling coil
Inside coil
Surface coil

5. Identify this type of coil.



Answer ____________________

Return to page 1-34, frame 6

9. No

10. Will an inside coil test the entire inside circumference of a tube at one time?

Yes ______ No ______

15. Yes

16. With differential coil arrangement the coils are wound such that they cancel out and give a zero indication.

True ______ False ______

21. Yes

22. Tubes and cylinders are the only specimens that can be tested with the absolute method.

True ______ False ______

You should not have turned to this page. The instructions were to return to page 1-34, frame 6, and continue with the review.

Return to page 1-34, frame 6.

10. Yes

11. To more accurately pinpoint the exact location of a discontinuity, which coil would you use?

    1. Encircling
    2. Inside
    3. Surface

Return to page 1-34, frame 12.

16. True

17. When we compare two separate places on the same specimen, we call it the ________-____________ method.

Return to page 1-34, frame 18.

22. False

23. Continue on to page 2-1.

There are, at present, many eddy current test instruments in use. Their design, many times varies considerably from theoretical standards but always for a specific test purpose. A few but not all of the instrument design variations will be presented in this chapter.

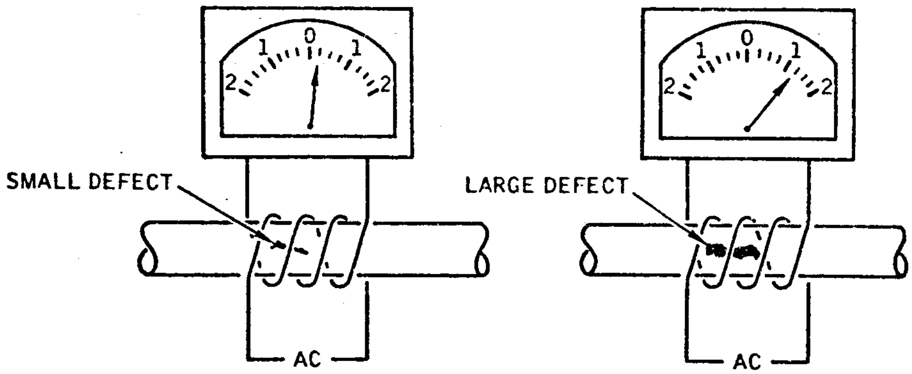
Since we have previously discussed the three main types of coils, (the encircling, inside, and surface coils) let's have a look at some of the methods of testing and the different test indications.

Impedance Testing - From Volume I you learned that impedance (the sum of reactance and resistance) is the total opposition to current flow in an ac circuit. Some of the eddy current test equipment is designed such (in its electrical circuitry) that it indicates the magnitude of the impedance changes in the circuit. In other words, it senses variations in magnitude of the circuit impedance. These variations in magnitude are, of course, caused by changes in the test specimen being evaluated. Any change in the specimen conductivity, magnetic permeability or dimension will effect changes in the test coil impedance. The magnitude of these changes is then sensed and displayed on a test meter or cathode ray tube (CRT). Generally speaking, most discontinuities such as cracks, holes, inclusions, porosity, dents, or unwanted dimension changes will change the test coil impedance.

Turn to the next page.

From page 2-1

The meter or CRT deflection is proportional to the magnitude of the variation. This means that if the defect is small, a small indication is received and a large discontinuity will give a correspondingly large indication at the meter or CRT.



A very important factor that must be remembered is that the indication reveals only one thing, that a change in impedance has taken place. It is not possible, using the impedance testing method, to identify from the test indicator which property of the specimen caused the impedance change. It could have been a crack, change in specimen size, change in alloy, or many other characteristics of the specimen, but the indicator still only sees an impedance change.

Impedance testing is often used to distinguish between cracks in the specimen and changes in diameter.

True . . . . Turn to page 2-3

False . . . . Turn to page 2-4

From page 2-2

True is the wrong answer - sorry! Any change in the specimen that will change its impedance will give an indication. From this indication it is impossible to tell whether the specimen has a discontinuity, crack, inclusion, or a change in its diameter. Changes in the specimens dimension cannot be distinguished from conductivity or permeability changes by the test instrument.

Turn to the next page.

False! Good, that's the correct answer. The indicator only indicates changes in the coil impedance and has no way of determining just what caused the change in coil impedance.

This is not a disadvantage however. Since the instrument is sensitive to these impedance changes, any significant change in dimension, conductivity, or permeability, would be worthy of display. Furthermore, the specimen could be evaluated further by other means or it may be rejected on the basis that whatever the cause of the impedance change was sufficient to reject the specimen.

The greatest disadvantage to impedance testing is that, because of equipment design characteristics, it is much more sensitive to dimensional changes than it is to conductivity or magnetic permeability. Thus, an indication may be caused by a very small dimensional change or a fairly large conductivity change. For example, a 1% diameter change in a cylinder would give the same indication as a 20% conductivity change. Since a 1% dimensional change is usually acceptable, a 20% conductivity change usually is not, and it would seem that the use of such equipment would be primarily in the search for dimensional changes or if used for conductivity variations the specimen dimension would have to be very constant.

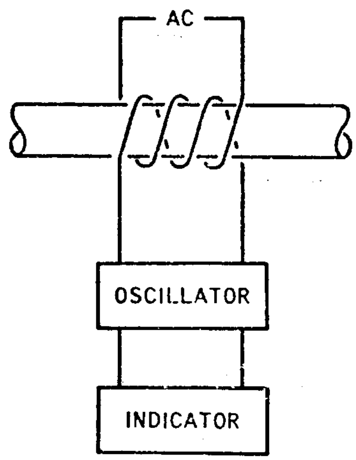
On the first page of this chapter we indicated that we would have a look at some of the methods of testing. From this would you expect that there would be other methods besides impedance testing?

Yes . . . . Turn to page 2-5

No . . . . Turn to page 2-6

Yes. Very good, you have again made the correct choice. There are other methods and the next one we will study is:

Reactance Testing - In the section of impedance testing we just discussed how a change in the coil impedance was monitored and displayed to indicate the presence of discontinuities or variations in the test specimen. With reactance testing we set up a somewhat different circuit arrangement. So that we don't get too involved with circuits, let's just say simply that we have added an oscillator to our equipment. From this oscillator we get our indication.



Rather than monitor the impedance change in the coil, we connect our indicator to the oscillator and monitor the frequency changes in the oscillator.

Can you identify the above coil arrangement.

Is this coil:

a double coil differential type . . . . Turn to page 2-7

a double coil absolute type . . . . Turn to page 2-8

From page 2-4

NO??? Holy Cow! We said we were going to have a look at some, and so we are. Actually, the next one will be Reactance testing.

Turn to page 2-5.

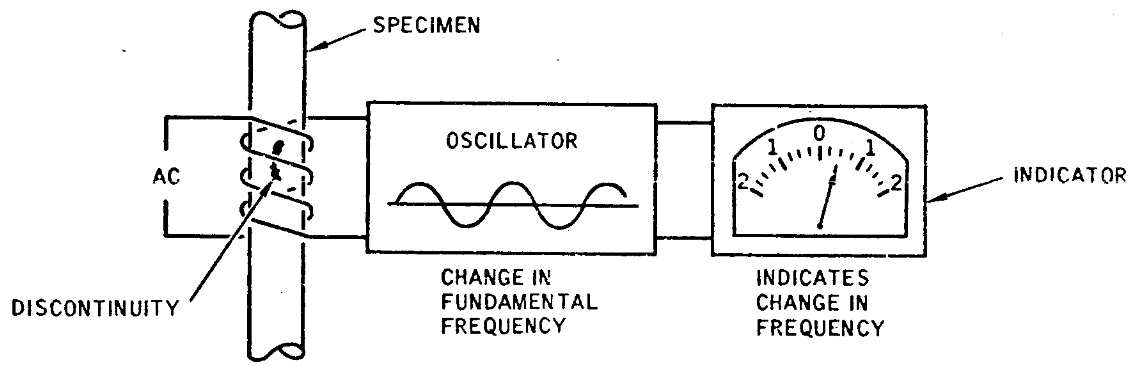
Have you forgotten already? It seems that you have. This is an absolute coil arrangement. As you can see, it makes no comparison and thus reads no difference. The differential coil, either the self-comparison or external reference, if you recall, makes a comparison and then indicates a difference.

If you are still unsure, check on page 1-28.

That is correct, your memory serves you well. It is a double coil absolute arrangement.

Of course, the circuit shown is simplified but it should give you the general picture necessary. Let's attack this thing and see if we can get the picture of how it works.

First of all, we will set up a fundamental frequency in the oscillator separate from the ac input. This is no problem, but for the time being forget the ac input and concentrate on the fundamental frequency at the oscillator. Our indicator will monitor this fundamental frequency and display any changes on a meter or CRT. Very good, now let's see what could cause this frequency to change. Let's start by saying that all physical discontinuities of the test specimen which register a change in the test coil will change the frequency in the oscillator. This change will then be displayed by the indicator.



This method of testing is called:

Impedance testing . . . . Turn to page 2-9

Reactance testing . . . . Turn to page 2-10

From page 2-8

Come come, impedance testing was the first one we studied. This method is reactance testing. We know; you're curious to know how reactance fits into this picture and what reactance is. Well, turn to page 2-10 and you will find out.

[redacted])

From page 2-8

Reactance testing is correct. Now it's time that we define the term reactance.

You had an exposure to reactance in Volume I, so you should know something about it. To refresh your memory - reactance is an opposition to the change in current flow. Let's see what happens. When we get a discontinuity or dimension change in the test specimen, we will get a change in eddy current flow in the area of the discontinuity. Now since reactance opposes changes in current flow, the whole arrangement is effected and the fundamental frequency at the oscillator will change. This in turn causes an indication on the meter or CRT.

This type testing will indicate, by a change in frequency, any variation of from 1% up; changes in conductivity, dimension, or permeability. Here is an example to give you some feel for reactance testing:

With the oscillator on our test coil set at a frequency of about 2900 cps (cycles per second), and an aluminum rod 1 inch in diameter being passed through the coil, a temperature change of 2°C to 3°C in the rod will change the frequency about 3 or 4 cps. This is due primarily to the conductivity change in the aluminum brought about by the change in temperature.

An eddy current test method which is based upon the specimen changing the frequency of the oscillator is called the . . .

. . . impedance testing method . . . . Turn to page 2-12

. . . reactance testing method . . . . Turn to page 2-11

That is correct, reactance testing method. In the impedance method, the equipment is sensitive to the impedance changes. But in reactance testing the equipment indicates any significant change in oscillator frequency.

The limitations of reactance testing, like impedance testing, makes it impossible to distinguish between conductivity, permeability, and dimensional changes. Also at certain frequencies, insignificant diameter changes of only 1% would give the same indication as a very significant crack with 5% depth.

With the information that you now have, which of the methods listed do you think could distinguish conductivity changes from dimension and permeability?

Impedance testing . . . . Turn to page 2-13

Reactance testing . . . . Turn to page 2-14

Feedback - controlled testing . . . . Turn to page 2-15

From page 2-10

Wrong choice. Impedance testing provides an indication when an impedance change is detected. Reactance testing indicates changes in oscillator frequency.

Return to page 2-1 and cover material again for reinforcement of these two methods.

From page 2-11

No, that's not correct. Impedance testing, as we have mentioned on the preceeding pages, will not distinguish between conductivity, permeability, and dimension changes in the specimen.

Return to page 2-11 and make another selection.

No, that's not correct. Reactance testing, as we have stated before, cannot distinguish between permeability, dimension, and conductivity changes in the test specimen.

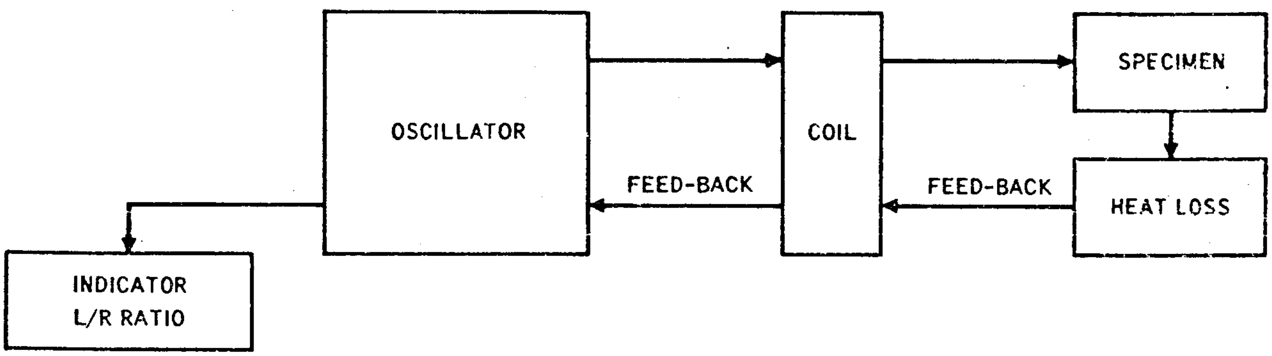
Return to page 2-11 for another try.

From page 2-11

Nice going! You remembered that neither impedance or reactance testing can distinguish between the three main variables (conductivity, permeability, and dimension). You chose feedback-controlled testing, which is the correct choice. It can distinguish between some variables. Let's find out how.

Feedback-Controlled Testing. A moment ago you learned that the impedance testing and reactance testing methods were unable to separate or distinguish dimensional (D) and permeability (u) changes from conductivity (σ) changes. From Volume I, we learned that the eddy current flow in the specimen will generate a certain amount of heat. This heat that is generated represents a loss of energy in the circuit. With this in mind, let's consider further. . . . .

In the feedback-controlled testing method we have a setup similar to this:



A brief description on the following page will show that the oscillator actually senses the ratio of inductance to resistance and displays this ratio on the indicator.

Turn to the next page.

The oscillator test frequency in the coil is induced into the specimen. There, due to the variables of the specimen, a heat loss takes place and a change in the I/R (inductance to resistance) ratio takes place. This new ratio is then sent back (feedback) to the coil and the oscillator and the new ratio is shown on the indicator. With the use of special feedback circuits, it is possible to eliminate or reduce the effect of inductance or the resistance whichever is desired. Then, in a certain instance, the ratio will change only when the desired variation in the specimen is present. Even though the test signal is usually indicated on a meter, this signal has horizontal and vertical components. By rotating the horizontal and vertical components it is also possible to make the resistance (conductivity) changes appear in the vertical direction. In this way all changes may, with selected feedback circuits, be directed on the vertical component. Thus the feedback circuits have separated the variables so that one variable or the other can be indicated separately on the meter.

On the past few pages we have studied which of the following:

CRT Vector Point Testing,

CRT Ellipse Testing, and

CRT Linear Time-Base Testing? . . . . Turn to page 2-17

Impedance Testing,

Reactance Testing, and

Feedback-Controlled Testing? . . . . Turn to page 2-18

From page 2-16

You read the question wrong, we have been studying:

Impedance Testing,

Reactance Testing, and

Feedback-Controlled Testing

However, we will now be studying:

CRT Vector Point Testing,

CRT Ellipse Testing, and

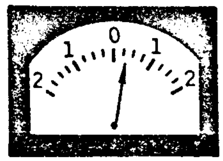
CRT Linear Time-Base Testing.

Turn to page 2-18.

That wasn't hard was it. The three testing methods just completed were:

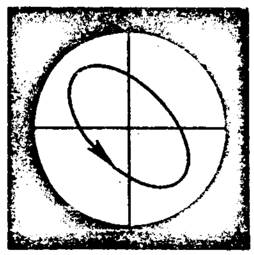
- Impedance,
- Reactance, and
- Feedback-Controlled.

Generally speaking, these three methods indicate test results on a meter. .



METER

. . . . rather than on a cathode ray tube (CRT).



CRT

A cathode ray tube could have been used in the above methods but to no particular advantage. The reason for this is, because of the nature of the three tests, no useful information can be received from the shape of the test signal. With the use of a meter, only the presence of a discontinuity and its relative size can be indicated.

If the shape or relative position of the test signal has information valuable to the test, it is necessary to use a. . .

meter. . . . . Turn to page 2-19

cathode ray tube . . . . Turn to page 2-20

It appears that you have missed the point. The question was, "If the shape or relative position of the test signal has information valuable to the test, it is necessary to use a. . ". You chose "meter" as your answer. The correct answer is "cathode ray tube" because the cathode ray tube will give information about the shape and position of the test signal, the meter will not. The meter only indicates two things:

1. A discontinuity exists.
2. Its approximate size.

Return to page 2-18 and try again.

From page 2-18

That's correct! The cathode ray tube will reveal (with proper circuits) things about the test signal that the meter will not.

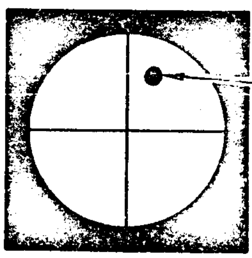
In the three methods that follow -

- Vector Point,
- Ellipse, and
- Linear Time-Base -

the relative position, shape or phase of the test signal can be meaningful in the evaluation of a test specimen. Each of these three methods display the test information on the screen of the cathode ray tube. This type of equipment is designed to reveal as much as possible about the test specimen and its discontinuities.

Vector Point Method. First on the list of the three cathode ray tube methods is the vector point. This, as the name implies, displays on the cathode ray tube a point rather than the expected wave shape.

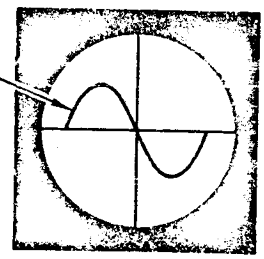
THIS



POINT

WAVEFORM

NOT THIS



The circuit design for vector point equipment is such that the signal from the test coils will always be displayed as a point of light.

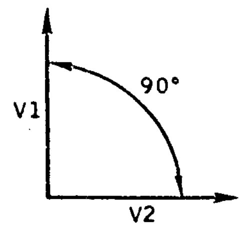
Do you suppose that if a discontinuity appears in the specimen that the point of light would change to a line or wave form?

Yes . . . . Turn to page 2-22

No . . . . Turn to page 2-21

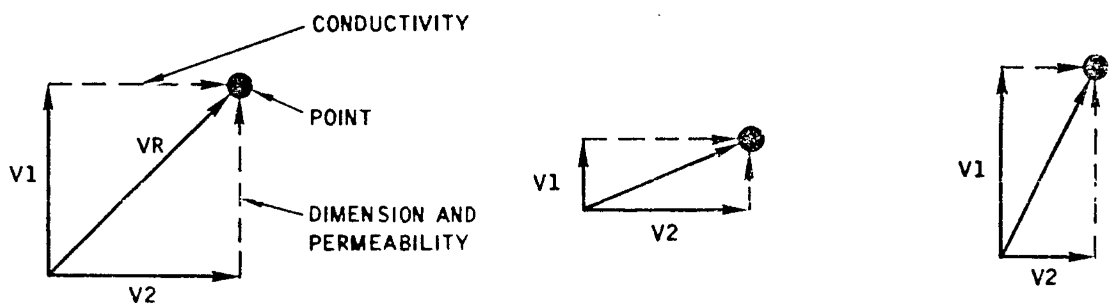
Excellent! The correct answer is no. It makes no difference what changes may appear at the test coils, the display will always be a point of light.

As you know from Volume I, the output of the test coil appears as two voltages (V1 and V2) and they are 90° out of phase.



V1 CORRESPONDS TO THE MAGNETIC AND DIMENSION CHANGES AND V2 THE CONDUCTIVITY CHANGES.

If these voltages were combined (by a special vector addition), their resultant (VR) would give a point thus:



As you can see, changes in the conductivity, dimension and permeability will change the position of the point.

With a change in dimension or permeability, would the point of light move

horizontally. . . . . Turn to page 2-23

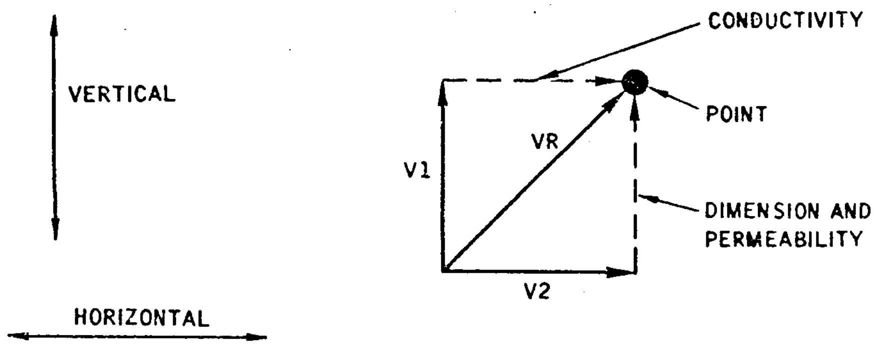
vertically . . . . Turn to page 2-24

That is incorrect. Your answer should have been no. The display, when using vector point equipment, will not change to a shape other than the point of light. This equipment is designed so that, no matter what the variations in the specimen might be, the display will be a point of light on the cathode ray tube.

Turn to page 2-21.

From page 2-21

"horizontally" is incorrect. Take another look at this illustration:



The question was "with a change in dimension or permeability, would the point of light move - horizontally"

- vertically"

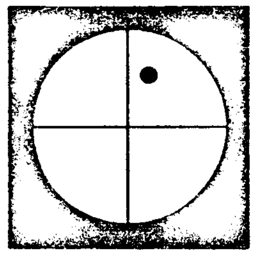
Well, as shown in the illustration, the dimension and permeability changes correspond to the vertical (up and down) movement of the point. Your answer should have been vertically for dimension or permeability changes.

Turn to page 2-24.

From page 2-21

"vertically" - That's right, good for you. You should now remember that vertical (up and down) changes are dimension and permeability changes in the specimen. Obviously, conductivity changes in the specimen will produce horizontal movements of the point. If there is no discontinuity in the specimen, the point will not move.

This point, as we have said before, is displayed on the cathode ray tube as a point of light.



The lines crossing at the center of the cathode ray tube make it possible to evaluate the type of discontinuity in the specimen and its magnitude.

In the Vector-Point Method, the indication then is on the CRT and is a point of light whose position will vary as the properties of the test specimen vary. The point will move vertically and horizontally.

If the vertical movement represents dimensional and permeability variations and the horizontal movement represents conductivity variations, is it possible to separate the conductivity properties of the specimen from other properperites by observing the point on the CRT?

Yes . . . . Turn to page 2-26

No . . . . Turn to page 2-25

Incorrect! The correct answer is "Yes". The question, "is it possible to separate the conductivity properites of the specimen from other properties by observing the point on the CRT", should have been answered - yes.

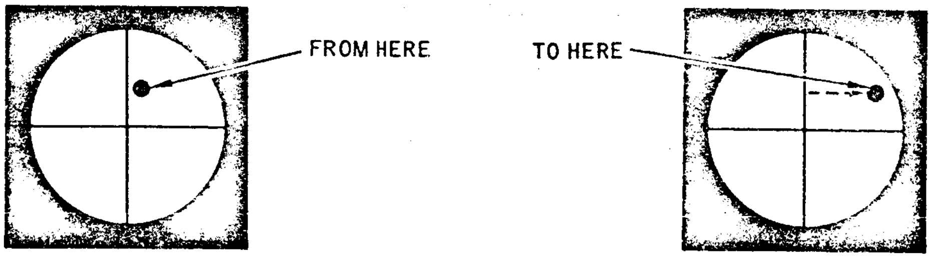
You see, on the previous page we learned that the conductivity variations of a specimen will move the point of light horizontally on the CRT. The dimension and permeability variations move the point vertically on the CRT. So it is possible to separate the two by observing the point on the CRT.

Turn to page 2-26.

[redacted])

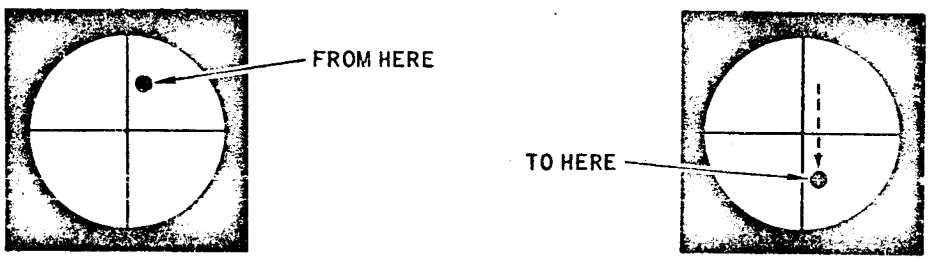
From page 2-24

Correct! It is possible to separate the conductivity properties from the other properties of the specimen. For example, If we have a discontinuity (conductivity change) in the specimen, the point on the CRT will move



HORIZONTAL

If we have a dimension change the point may move



VERTICAL

So you see it may move anywhere on the CRT and its movement will help identify the discontinuity in the specimen. As mentioned, if there is no discontinuity detected, the point will not move.

Is it possible to separate dimension changes from permeability changes?

Yes . . . . Turn to page 2-27

No . . . . Turn to page 2-28

[redacted])

Ooops - Sorry, that is not correct! Maybe you read the question wrong. You should recall from Volume I that you cannot separate dimension and permeability properties. Could you have been thinking of conductivity? You can separate conductivity from other properties (dimension and permeability).

Remember now?

Good, let's go back to page 2-26 and have another go at that question.

From page 2-26

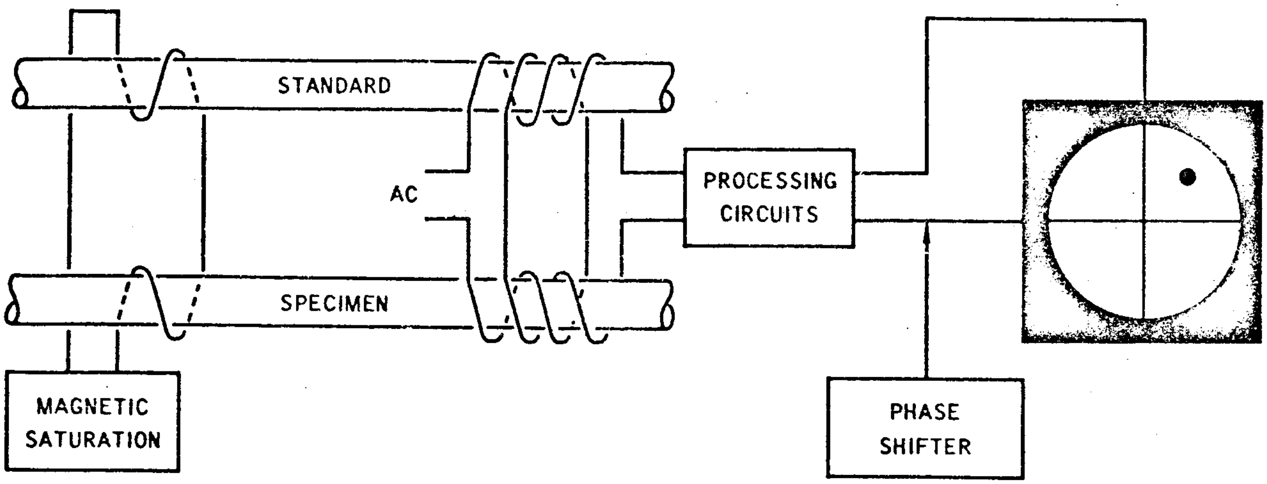
Correct! You remembered that dimension and permeability changes cannot be separated. They both move the vector point in the vertical (up and down) direction. Since the conductivity is perpendicular (90 degrees out of phase) it can be separated from the other properties.

Let's consider a situation where we want to test for conductivity variables and nothing else. First we have to eliminate the other variables (dimension and permeability) so we can easily identify conductivity discontinuities. If you recall, we can, by magnetic saturation of the specimen, eliminate permeability. Now all we have left are conductivity and dimension. Our next step is to do something about the dimensional properties. This is how it is done.

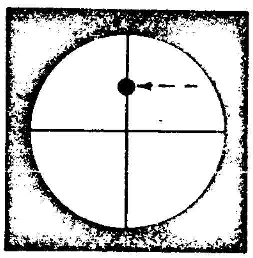
Turn to the next page.

From page 2-28

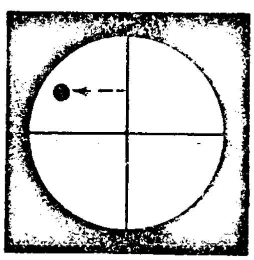
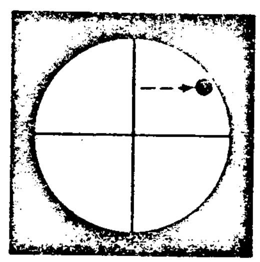
The illustration below shows a simplified diagram of our test set up.



With the standard and test specimen inside the test coils as shown and permeability eliminated by magnetic saturation, we get a point on the CRT. With the use of the PHASE SHIFTER control we can position the point of light so that it is on the vertical line -



Now any change in conductivity will move the point of light horizontally

LEFT  OR  RIGHT

The distance it moves will indicate the magnitude of the discontinuity.

Changes in dimension will move the point. . .

left or right . . . . Page 2-30

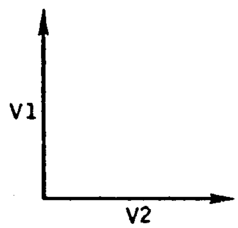
up or down on the vertical line . . . . Page 2-31

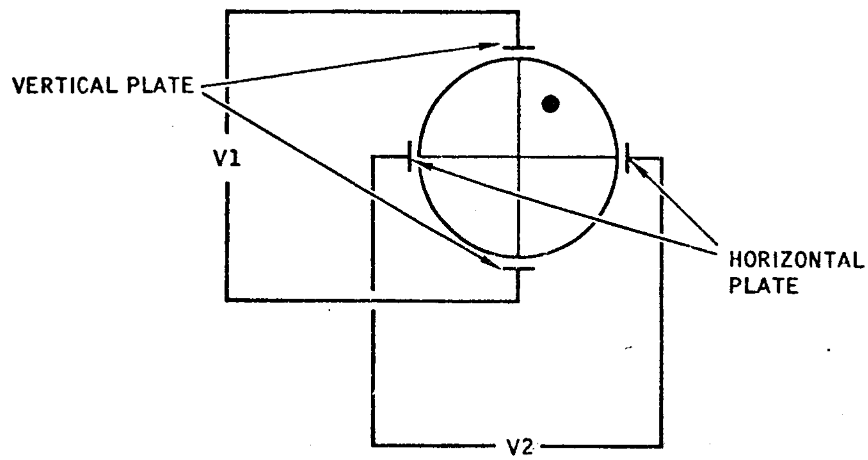
"left or right" is wrong. Conductivity changes will move the point left or right (horizontal) but the dimension changes will move the point up or down on the vertical line.

Better go back to page 2-29 and try that one again.

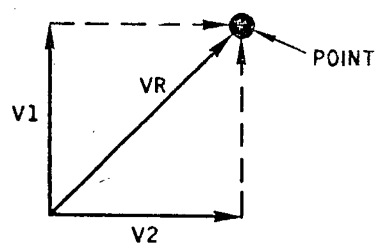
That is correct! Dimension changes in the specimen will move the point up or down on the vertical line. This same general method could be used when testing for dimensional variations by a simple re-arrangement of the equipment.

Ellipse Method. If you recall, in Volume I you were shown that the cathode ray tube had two vertical plates and two horizontal plates. With the Vector-Point Method, the value V1 was placed on the vertical plates and the value V2 was placed on the horizontal plates.





The resultant (VR), by special vector addition, was resolved and displayed as a point on the cathode ray tube.



In the ellipse method, would you expect the indication on the cathode ray tube to be a point of light similar to the Vector-Point Method?

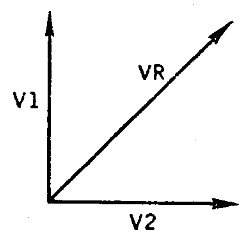
Yes . . . . Page 2-33

No . . . . Page 2-32

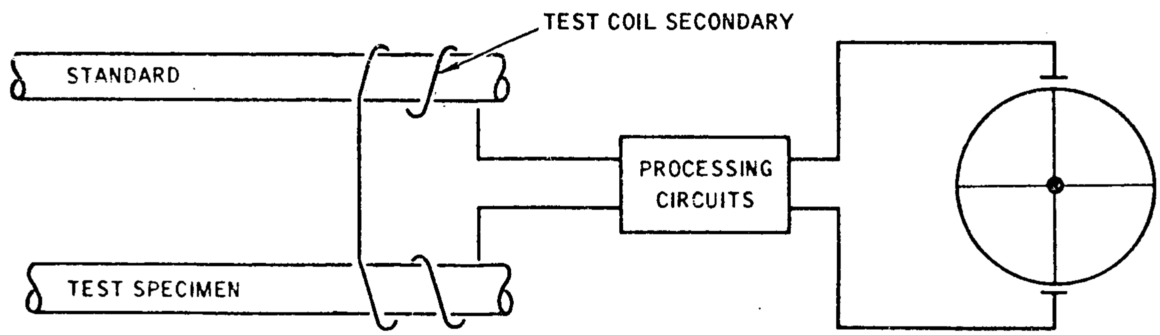
Don't know . . . . Page 2-34

"No" That's correct, you will not see a point, you will see an ellipse. We assume from your choice that you know what an ellipse is. If not, turn to page 2-34 for a quick look and then return here.

In the <u>ellipse method</u> the voltage VR (resultant) is placed on the vertical plates of the cathode ray tube.



When the two specimens are the same, a zero differential output will give us a point of light in the center of the cathode ray tube between the two vertical plates.

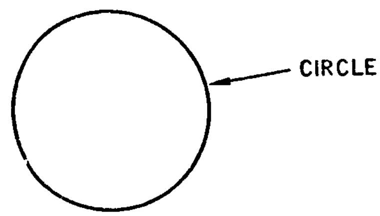


If we did not have a zero differential output from the coils, we would have a line between the. . .

vertical plates . . . . Page 2-35
horizontal plates . . . . Page 2-36

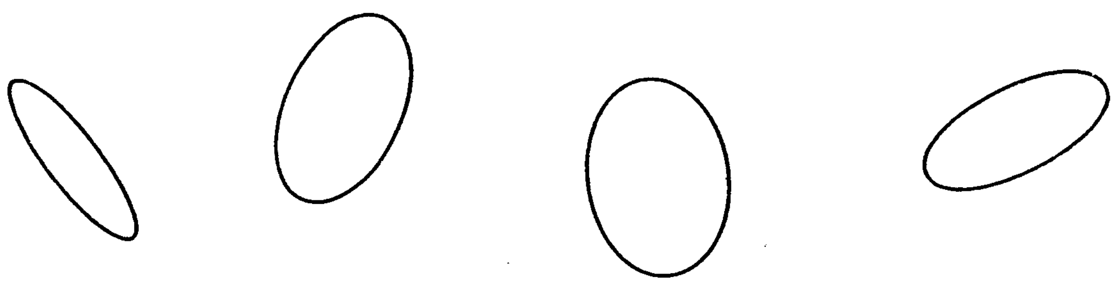
From page 2-31

That's incorrect! The correct answer is - no. The vector-point method displays a point. The ellipse method displays an ellipse. Do you know what an ellipse is? Well for those of you that do not, it is a circle or ring as it appears from an angle. If you look at a ring or circle, head-on, it looks like this:



If you look at a ring or circle from its side, it looks like this:

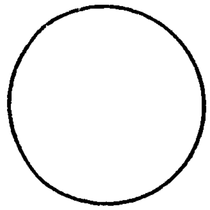
Now if you look at a ring or circle from any other angle, it becomes an ellipse.



These are shapes you will see on the cathode ray tube in the ellipse method.

Turn to page 2-32.

"don't know" - O.K. let's find out. Since the vector-point method shows a point, it seems natural that the ellipse method would display an ellipse on the cathode ray tube. An ellipse is really just a ring or circle as it appears from different angles. If you look at a ring or circle head-on, it looks like this:



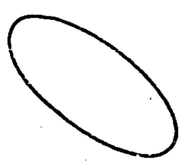
If you look at the same ring from its side, it looks like a line:

Now if you look at the ring from any other angle, it becomes an ellipse.

In the ellipse method you are actually seeing a ring on the cathode ray tube; but you see it either from the side. .

A LINE

or from an angle.

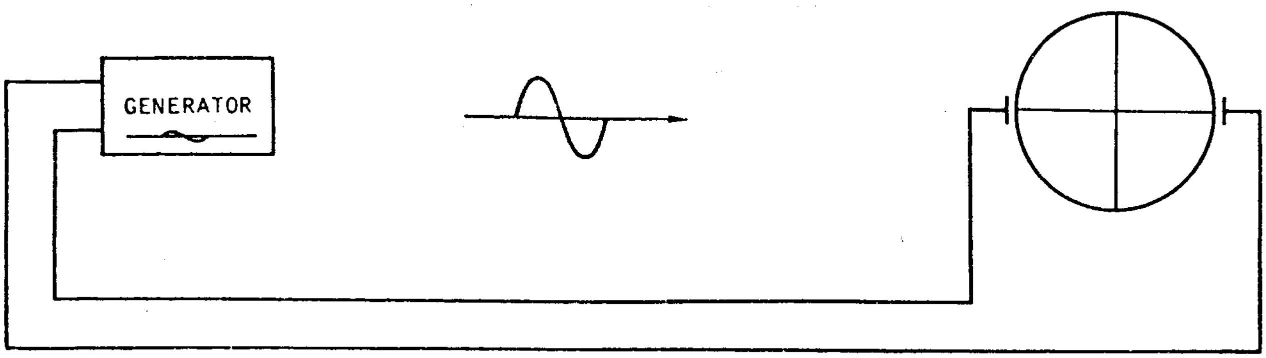


AN ELLIPSE

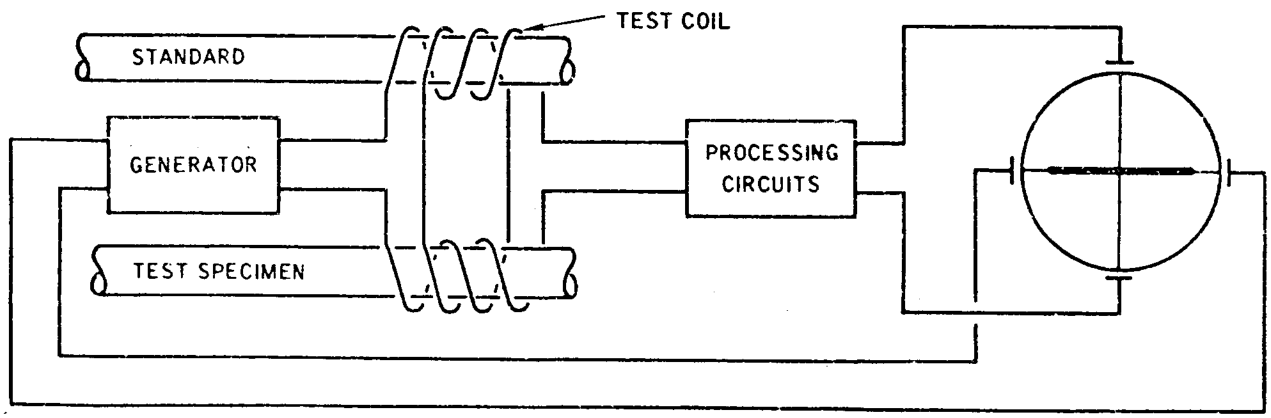
Turn to page 2-32.

That's correct! We would have a line (up and down movement of the point) between the vertical plates.

Now what are we going to do about the horizontal plates? Well let's put an ac signal from the signal generator on the horizontal plates.



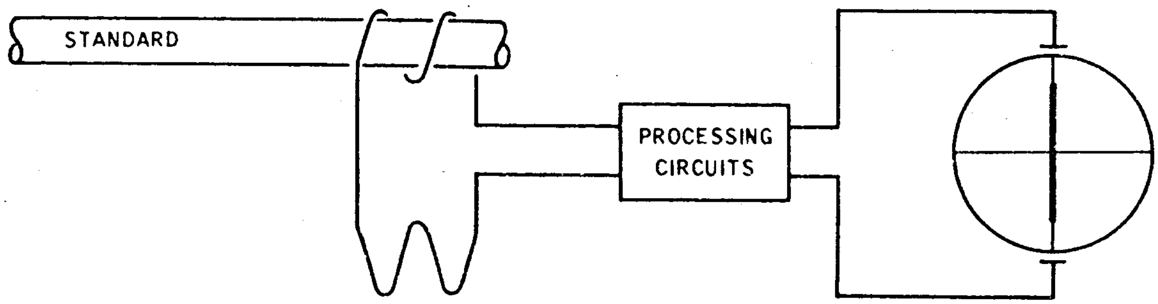
This would give us a line between the horizontal plates of the CRT caused by the point being moved back and forth by the ac voltage from the generator. So now we have:



If the display on the CRT is not positioned properly, we can position it by adjusting the. . .

PHASE SHIFTER . . . . Page 2-37
CHANNEL SELECTOR . . . . Page 2-38

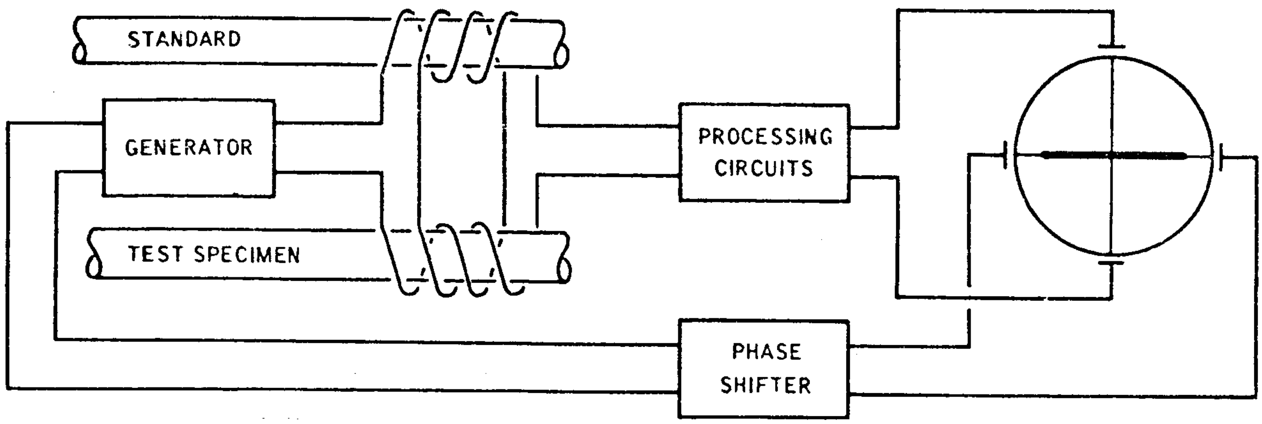
That's wrong! We would have a line (up and down movement of the point) between the vertical plates.



As yet we have nothing applied to the horizontal plates, and the differential signal from the test coils will just move the point up and down between the vertical plates.

Turn to page 2-35 for the next exciting episode.

"PHASE SHIFTER" Very good, that is correct. The phase shifter serves the same purpose for the ellipse method as it did for the vector-point method. It positions the display horizontally on the cathode ray tube. And with the PHASE SHIFTER added, our illustration is complete.



Now let's get down to the real business at hand. What do we see on the CRT and what does it mean?

Let's see how good your memory is. Will the ellipse method of eddy current testing separate or distinguish conductivity from dimension - permeability.

Yes . . . . Page 2-39

No . . . . Page 2-40

From page 2-35

Sorry, these cathode ray tubes are not TV sets. And as yet, most ellipse method CRT's do not have channel selectors.

Your choice should have been PHASE SHIFTER.

Turn to page 2-37.

Good! You remembered. <u>The ellipse method, like the vector-point method and the linear time-base method, will separate the conductivity from the other variables.</u>

We have said that we can separate the variables so now we will show you how. But first, since the dimension and permeability variables will have the same effect on the CRT display, it would be much simpler if we eliminated the permeability variable so that only dimension changes would be displayed. We can do this the same way we did in the vector-point method by placing a strong magnetic field around the standard and test specimens. This is called magnetic saturation and will cancel out any permeability variation in the test.

Now the only variables left are conductivity and dimension.

With the ellipse method we can see any discontinuity or variation caused by either of these variables.

By the use of magnetic saturation the <u>test coil</u> will respond to. .

Dimension and permeability. . . . . Page 2-41
Conductivity and permeability . . . . Page 2-42
Conductivity and dimension . . . . Page 2-43

From page 2-37

You must have forgotten. The ellipse method, like the vector-point method and the linear time-base method, will separate the conductivity from the other variables.

Turn to page 2-39.

From page 2-39

Wrong - "Conductivity and dimension" is the correct answer. Magnetic saturation will eliminate permeability effects on the test coil.

By the use of magnetic saturation, regardless of the magnetic properties of the specimen under test, the magnetizing effect of the magnetic field will reduce to essentially zero the effects of the permeability variable. Thus, if we saturate (magnetically) all of the test specimens, we have in effect removed one variable.

Return to page 2-39 and try again.

[redacted])

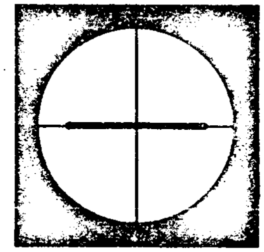
Wrong - "Conductivity and dimension" is the correct answer. Magnetic saturation will eliminate permeability effects on the test coil.

By the use of magnetic saturation, regardless of the magnetic properties of the specimen under test, the magnetizing effect of the magnetic field will reduce to essentially zero the effects of the permeability variable. Thus, if we saturate (magnetically) all of the test specimens, we have in effect removed one variable.

Return to page 2-39 and try again.

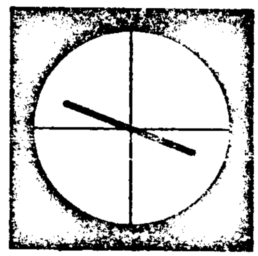
Correct! Conductivity and dimension are the only variables left when magnetic saturation is used to eliminate the permeability variable.

As you may recall from a few pages back, the display on the CRT will be a straight line.



This condition indicates that there is an ac signal on the horizontal plates and zero differential voltage (standard and test specimen are the same) from the test coils on the vertical plates.

Now let's see what happens when we get a change in dimension. After all of our discussion you probably expect to see an ellipse on the CRT - but not yet. A change in dimension will just tilt the horizontal line as shown in this illustration.



A dimension change will not noticably change the phase of the signal on the test coil, but it will give a difference in voltage. So now we no longer have a zero differential from the test coil. We have a voltage difference, but the test signal is still in phase with the signal on the horizontal plates. Thus our straight line remains straight but is inclined. A straight line results because, when two voltages having the same phase are applied simultaneously to the horizontal and vertical plates of the CRT, a straight line will result.

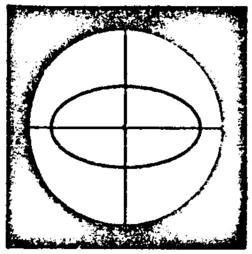
A dimension change will display an. . .

inclined straight line. . . . . Page 2-44
ellipse . . . . Page 2-45

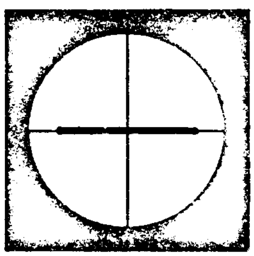
From page 2-43

Nice going! You got the right answer. A dimension change (tube diameter, thickness or shape) will give an inclined straight line on the cathode ray tube.

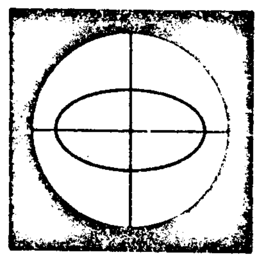
Suppose that rather than a dimension change we have a crack or discontinuity in the specimen that gives us a conductivity change in the coil. Ah ha! Now we get an ellipse - finally.



Yes, an ellipse is displayed on the cathode ray tube when the specimen discontinuity gives a conductivity change in the coils. However, unlike the dimension change, we now get a phase change on the signal to the vertical plates rather than a voltage change. This phase change causes the horizontal straight line to open up into an ellipse.



NO DEFECT



CONDUCTIVITY DEFECT

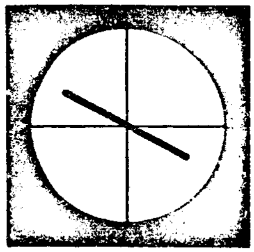
At this point would you say that by using the ellipse method, it is possible to separate the conductivity variable from the dimension variable?

Yes . . . . Page 2-46

No . . . . Page 2-47

From page 2-43

You should know better than that. A dimension change will display an inclined straight line on the CRT.



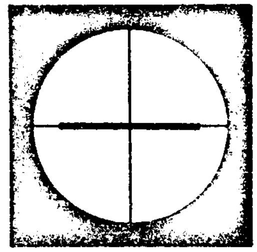
Not an ellipse.

Turn to page 2-44.

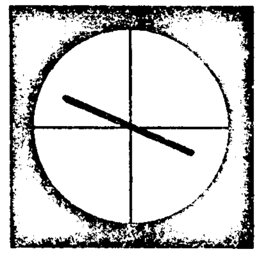
[redacted]

By George, that's right! You remember. A dimensional change in the specimen will display an inclined straight line on the cathode ray tube and a conductivity change in the specimen will display an ellipse on the cathode ray tube. At this point then, we have the following displays that have definite meaning:

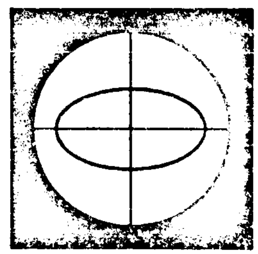
NO DISCONTINUITIES
(DIFFERENTIAL COIL BALANCE)

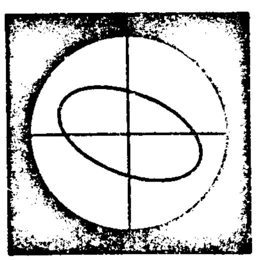


DIMENSIONAL DISCONTINUITIES
(VOLTAGE CHANGE)



CONDUCTIVITY DISCONTINUITIES
(PHASE CHANGE)





If a display on the cathode ray tube looked like this, would you suspect. . . .

a dimensional discontinuity . . . . Page 2-48

a conductivity discontinuity . . . . Page 2-49

both a dimension and a conductivity discontinuity . . . . Page 2-50

From page 2-44

That's not right! The ellipse method will separate conductivity and dimensional changes. Remember, a dimensional change will display an inclined straight line and a conductivity change will display an ellipse.

Turn to page 2-46.

[redacted])

From page 2-46

That's only partially right. You recognized that the display was inclined and that's good. That means that there is a dimension change. However, you should have noted that it is not a straight line but is an ellipse. Since an ellipse indicates a conductivity change we can only draw one conclusion and that is that we have <u>both</u> dimension and conductivity discontinuities.

Turn to page 2-50.

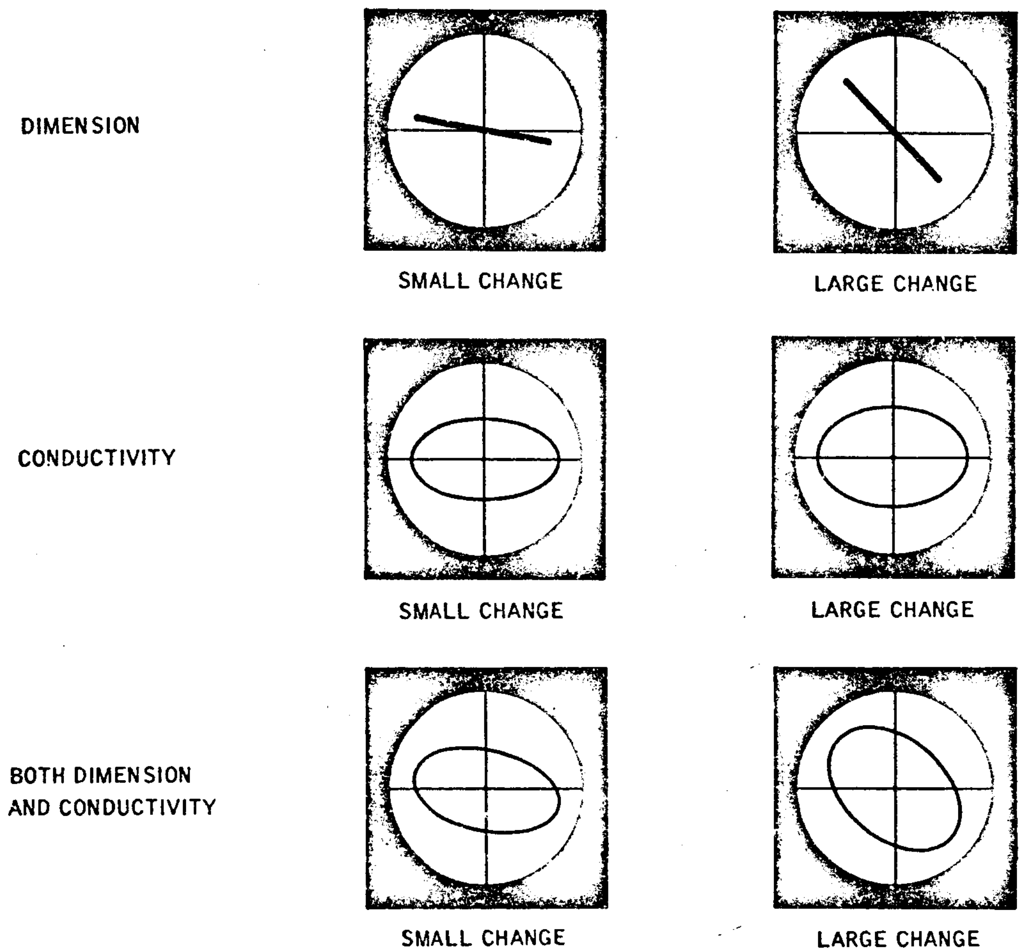
From page 2-46

That's almost right. You recognized that the display was an ellipse and that's good. That means that there is a conductivity change. However, you should have noted that it is not on the horizontal line but is inclined. Since an inclined display indicates a dimension change we can only draw one conclusion and that is that we have both dimension and conductivity discontinuities.

Turn to page 2-50.

Very good! An ellipse indicates conductivity changes and the inclined axis of the ellipse indicates a dimension change so we must therefore have both.

Without spending too much more time, it would be well to mention here that a great deal can be learned about the specimen by an experienced operator using the ellipse method. For example, by observing the relative position and shape of the CRT display, it is possible to determine just how much the dimension has changed. It is also possible to determine the approximate depth and length of a discontinuity. This is done by observing the angle of inclination for dimension changes and the size of the opening of the ellipse for conductivity.



Turn to the next page.

From page 2-50

Linear Time-Base Method

In Volume I you had a good introduction to the linear time-base method of eddy current testing. If you recall, this method in some respects is like the ellipse method in that two separate signals were placed on the vertical and horizontal plates of the cathode ray tube.

Assuming a similar condition, that of using differential coils (coils in opposition), we will have a signal from the coils that will indicate the presence of any discontinuity in the test specimen. This signal will be placed on the vertical plates of the cathode ray tube just as it was in the ellipse method. However, a different type of signal will be placed on the horizontal plates in the linear time-base method. This different type of signal is a saw-tooth shaped signal. (NOTE - These illustrations are signals placed on the horizontal plates, they are not displayed on the CRT.)

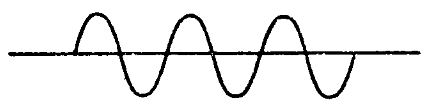
SAW-TOOTH VOLTAGE

LINEAR TIME-BASE METHOD

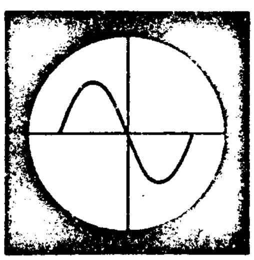
If you recall the horizontal signal in the ellipse method was an ac . . .

SINUSOIDAL VOLTAGE

ELLIPSE METHOD



With a signal from the test coil on the vertical plates, which of the above signals would give a display like this, if placed on the horizontal plates?

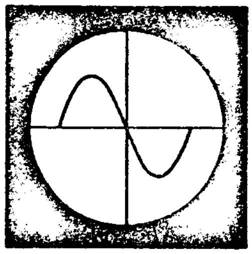


(Be careful, this is tricky)

Saw-tooth voltage . . . . Page 2-53
Sinusoidal voltage . . . . Page 2-52

That's wrong! See there, we told you it was tricky. You picked sinusoidal because the two waves look the same but you forgot that the sinusoidal wave gives an ellipse when placed on the horizontal plates and combined with the vertical plate signal.

To get a signal like this:



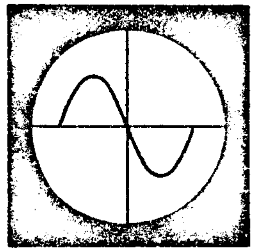
we must have a saw-tooth voltage on the horizontal plates.

Turn to page 2-53.

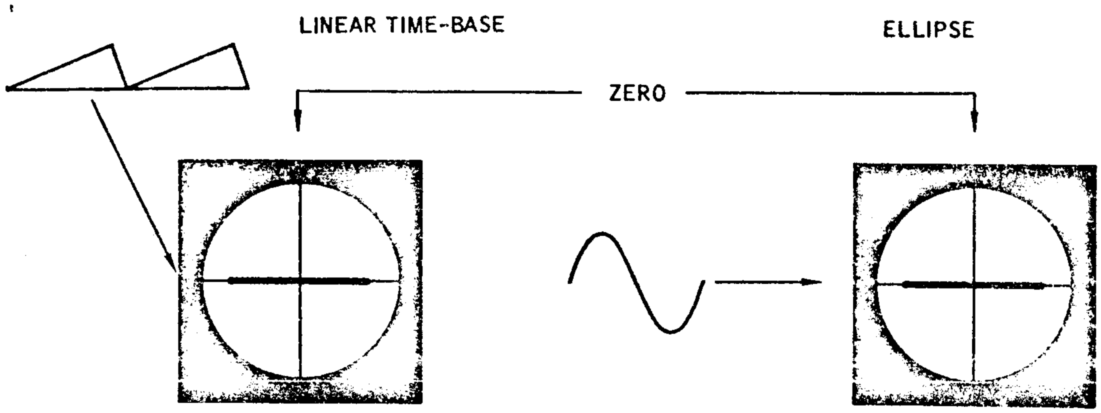
[redacted]

From page 2-51

Good! You made the correct choice. The sinusoidal waveform gave us an ellipse in the ellipse method so the saw-tooth must give us this waveform . . .

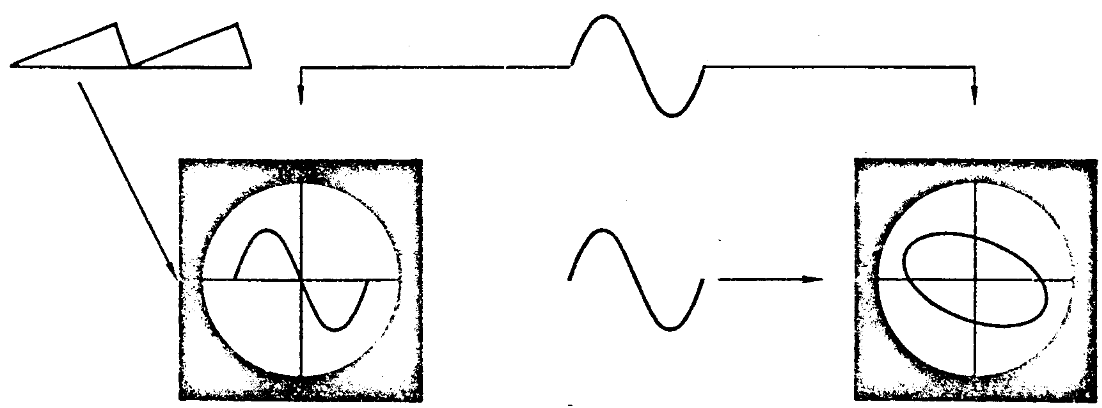


Now this of course requires a signal on the vertical plates, otherwise we would get a straight line . . . Let's compare the linear time-base and ellipse methods . .



NO DISCONTINUITIES

That's right, they are the same with no discontinuities in the test specimen. But . . .



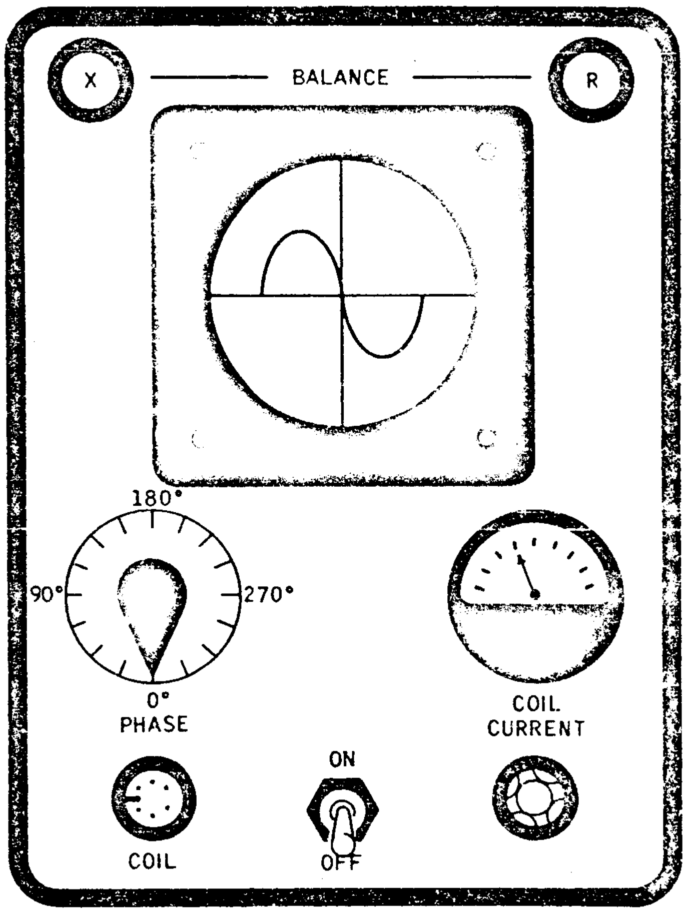
WITH DISCONTINUITIES

As you can see we will have an ac waveform on the CRT with linear time-base method when a discontinuity exists in the test specimen.

Turn to page 2-54

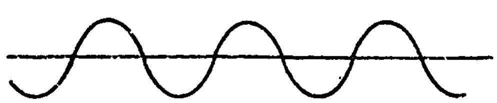
The saw-tooth voltage acts as the time base. That is, it is applied to the horizontal plates such that it displays one cycle of the signal (from the vertical plates) across the CRT, giving the ac sinusoidal waveform.

Let's take a moment and find out what some of the controls (on typical linear time-base equipment) are designed to do.



Which of the two waveforms shown below is applied to the horizontal plates of the linear time-base CRT.

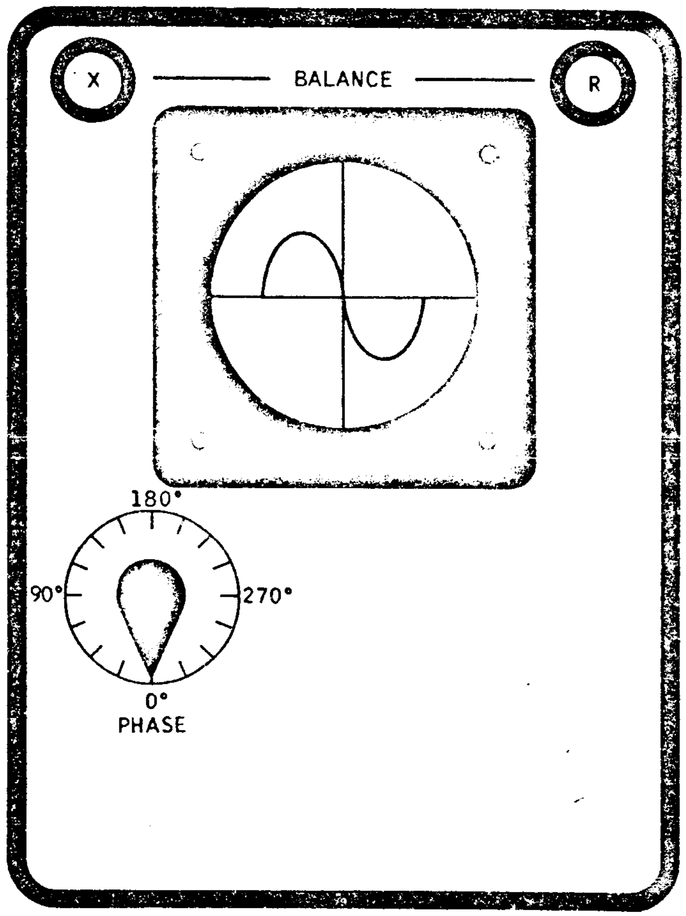
 . . . . Page 2-55

 . . . . Page 2-56

From page 2-52

That's right! Very good. The saw-tooth is correct. With a saw-tooth signal on the horizontal plates a sinusoidal (ac) waveform will be displayed on the CRT.

The controls mentioned (and illustrated) on the previous page help the operator adjust and position the signal that is displayed on the CRT. Of course on most equipment we will have an ON-OFF switch, a receptacle to connect the COIL, a meter to indicate the COIL CURRENT, and a current adjustment. That leaves the X and R BALANCE controls and the PHASE shift control.



Which of the controls (BALANCE or PHASE) would not shift the phase of the signal on the CRT?

X and R BALANCE . . . . Page 2-57

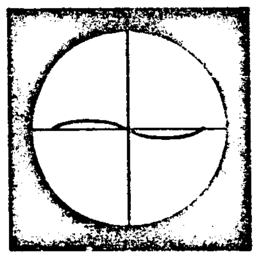
PHASE . . . . Page 2-58

Wrong choice - the ac (sinusoidal) waveform is used with the ellipse method. The saw-tooth is used with the linear time-base equipment. The saw-tooth should have been your choice.

Turn to page 2-55.

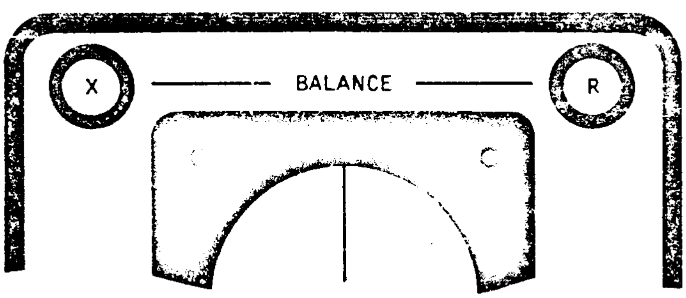
X and R BALANCE. That's correct! This control will not shift the phase of the signal on the CRT. Let's see what the BALANCE controls do.

As you recall from Chapter 1, the differential coils are in opposition such that their signals oppose each other and give a zero output. This is only theoretically correct. Actually, they are not quite zero but may look like this:

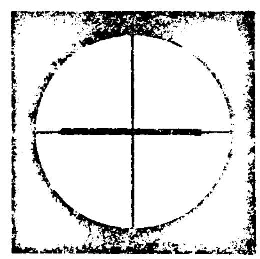


FROM THIS

By adjusting the BALANCE controls, these signals can be smoothed out to become nearly a straight line.



TO THIS



The smoother this line becomes the better the results will be on the test.

Which of the controls (BALANCE - PHASE) will shift the phase of the signal on the CRT?

BALANCE . . . . Page 2-59
PHASE . . . . Page 2-60

Not correct - Sorry, but the PHASE control will change the phase of the signal on the CRT. The question was "Which of the controls (BALANCE or PHASE) would not shift the phase of the signal on the CRT?" Your answer should have been X and R BALANCE.

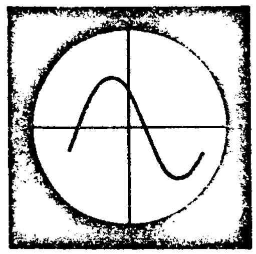
Turn to page 2-57.

"PHASE" - should have been your answer. The BALANCE controls are designed to smooth out the signal on the CRT. That is, if the zero line on the CRT is not straight and smooth, the ripples in the line may cause faulty indications when a discontinuity does come along.

Return to page 2-57 and read it again.

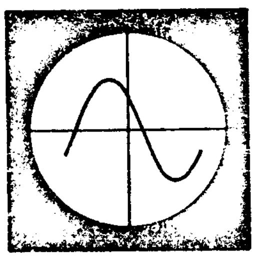
From page 2-57

"PHASE" Correct again. The PHASE control shifts the signal left and right on the cathode ray tube. In the original setup the coils are unbalanced by placing only one specimen in the coils rather than two. This gives a signal like this:

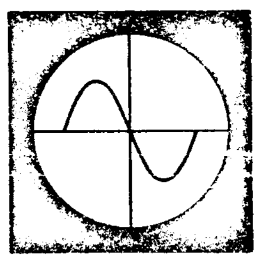


As you can see it is not properly centered on the tube. By adjusting the PHASE control, the signal can be moved left or right to the desired position.

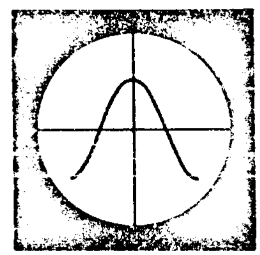
FROM THIS

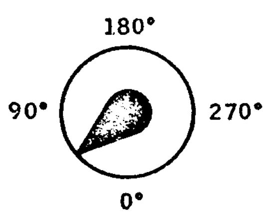


TO THIS

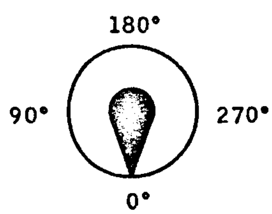


OR THIS

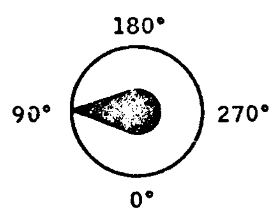




PHASE



PHASE



PHASE

Now you can see that by use of the BALANCE and PHASE control, we can change the shape and position of the signal that is displayed on the cathode ray tube.

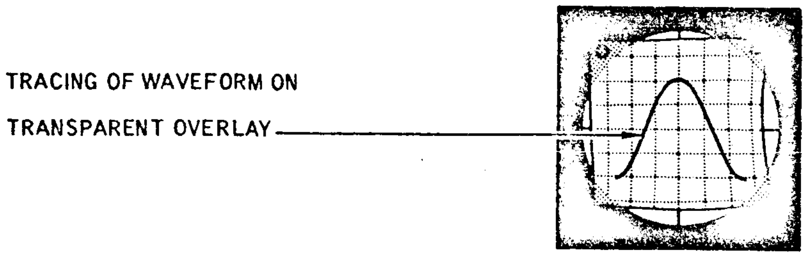
Turn to the next page.

From page 2-60

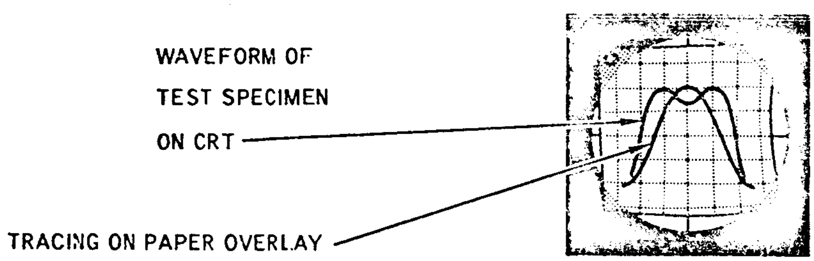
Now you are ready to start back through the book and read those upside-down pages.

From page 2-60

Now let's look at the waveform and how it can be evaluated for test information. In one situation using the linear time-base method, the controls are adjusted with a standard specimen in the coils so that a waveform appears on the screen. A transparent paper overlay is placed on the screen and a tracing is made of the waveform on the screen.

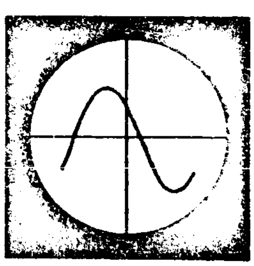


Then the standard specimen is removed from the coil and test specimens are put into the coil. The waveform of the test specimen can then be seen through the transparent paper overlay and compared to the tracing on the paper.



As you can see, any discontinuity in the test specimen will appear different from the tracing. With this method, different types of discontinuities can be detected.

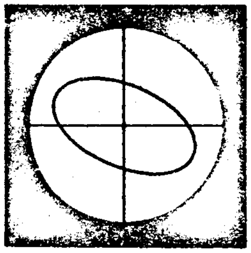
Which of the three cathode ray tube (CRT) methods is illustrated below?



Linear time-base . . . . Page 2-63
Vector point . . . . Page 2-64
Ellipse . . . . Page 2-62

From page 2-61

Your choice "Ellipse" is incorrect, if you recall the ellipse method gives a display on the cathode ray tube like this:

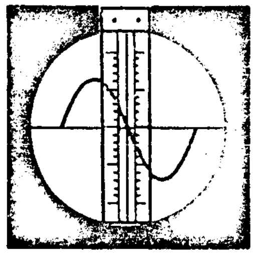


The waveform displayed on page 2-61 was from the Linear time-base method.

Return to page 2-61 and try again.

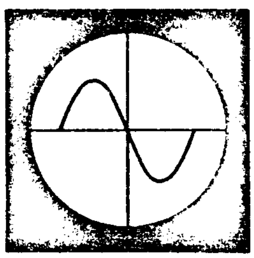
Excellent! Linear time-base method is the right answer. The other two listed are of course displayed as a point or an ellipse on the CRT.

Another situation or arrangement using the linear time-base method is the slit technique. In this setup, a narrow slit is placed in front of the cathode ray tube thus:



Now then, as the waveform changes position on the cathode ray tube, an evaluation is made through the slit to determine what discontinuities or changes in the specimen are taking place. Of course with this narrow slit, the side motion (left and right) will not be observed. Only up or down motion will be noticeable in the slit.

Now what we have just said is tricky. Imagine for a moment a waveform on the cathode ray tube without the slit.



After calibration of the equipment, this waveform should not move up or down when a discontinuity appears in the specimen.

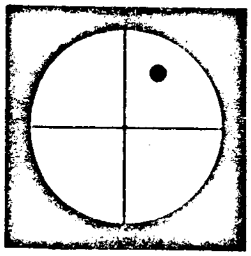
With a shift in phase the waveform will move . . .

. . . up or down . . . . Page 2-65

. . . left or right . . . . Page 2-66

From page 2-61

Your choice "Vector point" is incorrect, if you recall the vector point method gives a display on the cathode ray tube like this:



The waveform displayed on page 2-61 was from the Linear time-base method.

Return to page 2-61 and try again.

From page 2-63

No! A shift in phase of the signal or waveform on the cathode ray tube will move the waveform left or right and if you recall it can be adjusted by the PHASE control on the <u>linear time-base</u> equipment.

Remember a phase shift will shift the waveform sideways on the cathode ray tube.

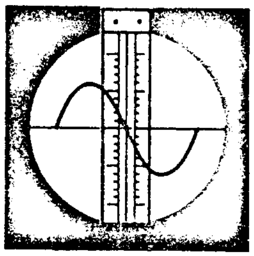
Turn to page 2-66.

[redacted])

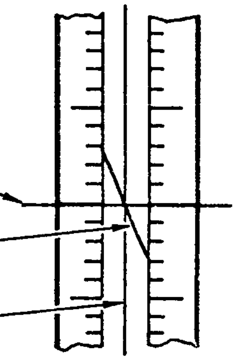
From page 2-63

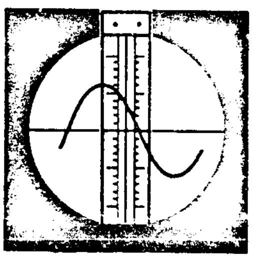
That's right! A phase shift will move the waveform left or right.

About this time you may be kind of confused. We just got through saying that the slit will only show up and down movement. How then can we see a phase shift? Well, it's really quite simple. Have a look:

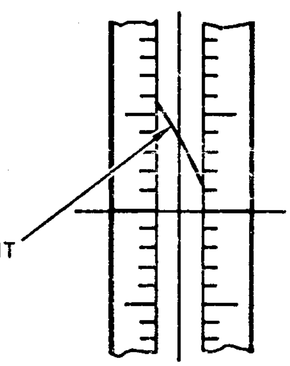


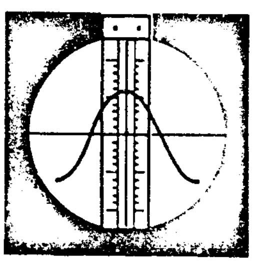
With the waveform adjusted so that it goes through zero, where the horizontal and vertical lines cross, we will see this in the slit . . .



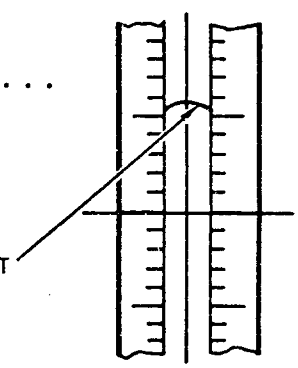


If the waveform shifted 45 degrees to the right, the value at the slit will go up . . .





Then if the waveform shifted 45 degrees more to the right the value at the slit will go up still farther . . .

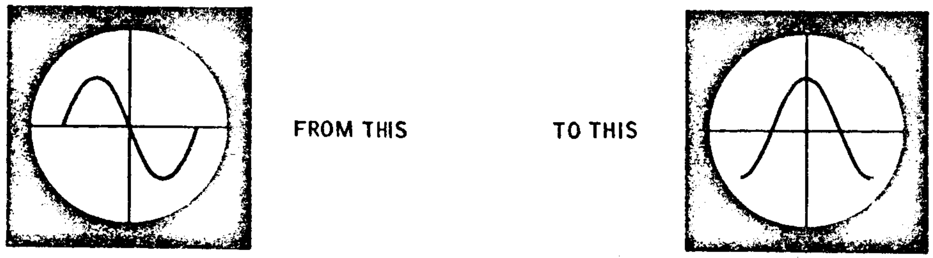


The waveform on the CRT . . .

. . . moves up or down . . . . Page 2-67

. . . shifts left or right . . . . Page 2-68

You missed the point. You see, the waveform is moving sideways on the CRT.



But, viewing through the slit, the waveform will <u>appear</u> to move up or down.

Return to page 2-66 and try again.

From page 2-66

Very good! The waveform on the cathode ray tube shifts left or right. It moves up and down when viewing the waveform through the slit.

By marking the slit like a ruler (up and down its sides) it is possible to determine the magnitude of the discontinuity by the change in the slit value.

Have you thought about how we can separate the conductivity from the dimension and permeability? Well we said we could before and we can here also. You of course recall that the dimension effects and conductivity effects are 90 degrees apart. When using this same principle we adjust the equipment such that the dimension and permeability effects are along the horizontal line and conductivity is along the vertical line. With this arrangement, the dimension and permeability effects will show little or no change in the slit value because the waveform will shift very little with dimensional discontinuities. However, conductivity will shift the phase of the waveform extensively (depending on the magnitude of the discontinuity) and thus the slit value will change very noticeably with conductivity changes.

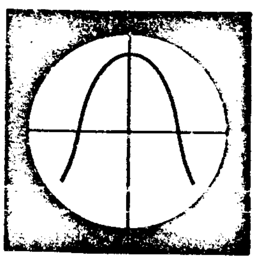
By adjustment of the controls this arrangement can be changed such that the conductivity effect is on the horizontal line and dimension or permeability effects will be displayed at the slit.

Turn to the next page.

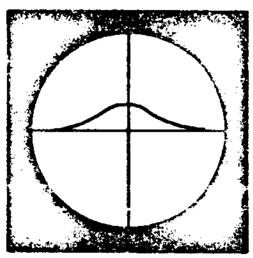
From page 2-68

Another use or application for the linear time-base equipment is that of sorting. With this equipment it is possible to sort parts according to their dimension, hardness, alloy composition, tensile strength, and heat treatment.

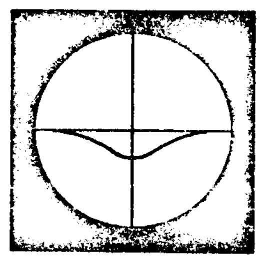
Let's use for our discussion "alloy composition". Assume that we have many special metal pins that are made of four different alloys of a metal. How they got all mixed together no one knows. But now we have to sort them for specific uses. If they all look just alike, we will have to use our eddy current linear time-base sorting equipment. Without going through all of the details, let's assume that the equipment is all set up - BALANCE and PHASE controls are adjusted and we are all set to go. The four different alloys will make four different waveform displays on the cathode ray tube.



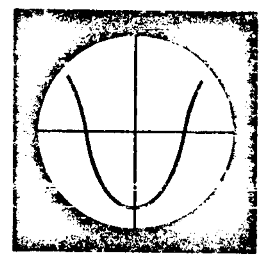
1



2

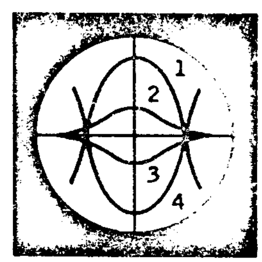


3



4

We place a transparent overlay on the CRT and trace the four waveshapes on the overlay and identify them. Now all we have to do is run the rest of the metal pins through the equipment and compare the waveform on the CRT with that on the overlay. It is possible to use this sorting equipment in many other effective ways.



Do you think it's possible to get information displayed that is not important to the test or inspection?

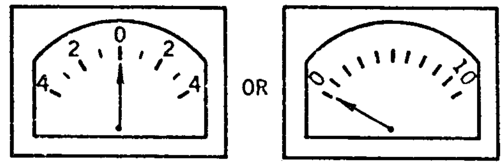
Yes . . . . Page 2-70

No . . . . Page 2-71

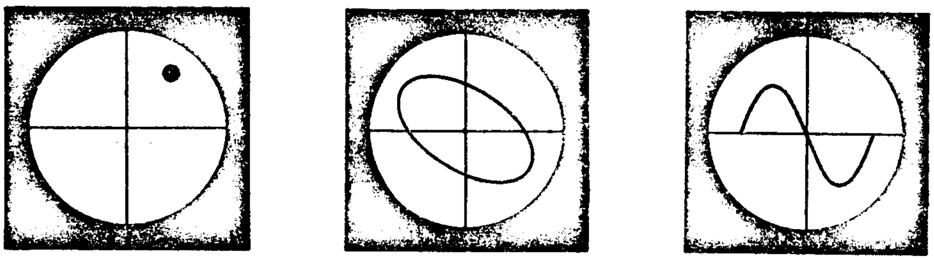
Yes! Information of no value can be received on the cathode ray tube and many times this excess or unimportant information will actually hide the important test information.

Modulation Analysis

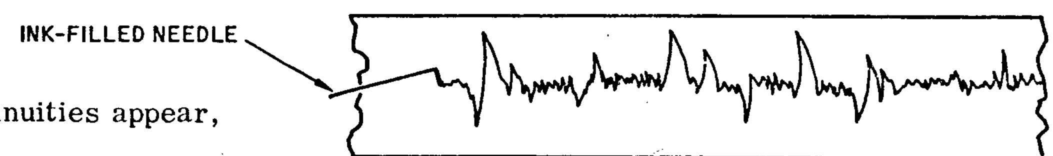
Another type of display comes into use now. If you recall earlier, displays or indications were on meters . . . .



Then when we studied vector point, ellipse, and linear time-base methods the cathode ray tube was used.



Finally with the study of modulation analysis we use the chart recorder. The chart recorder is simply a special paper that records the deflection of a pen or sensitive needle that marks the paper as it is deflected when discontinuities are observed.



As the discontinuities appear, the needle swings back and forth marking the paper chart.

The chart recorder is used with which eddy current test method?

Ellipse . . . . Page 2-72
Linear time-base . . . . Page 2-73
Modulation analysis . . . . Page 2-74

[redacted])

From page 2-69

Sorry! You're wrong. It is possible and quite common to have information on the cathode ray tube that is not important to the test. If we are looking for cracks, and a dimension change comes along the display may be changed just enough to give a false indication.

Turn to page 2-70.

[redacted])

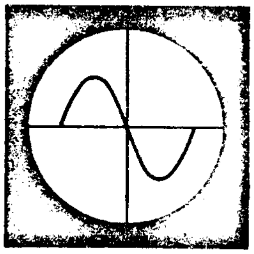
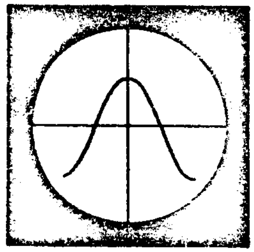
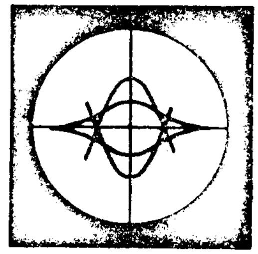
From page 2-71

No, the ellipse method displays an ellipse on the cathode ray tube. The chart recorder (paper strip with lines recorded by a signal-sensitive needle) is used with the modulation analysis method of eddy current testing.

Turn to page 2-74.

From page 2-71

Linear time-base is not correct, this method uses the cathode ray tube and if you recall, displays variations of the ac (sinusoidal) waveform.

The chart recorder is used with the modulation analysis method of eddy current testing.

Turn to page 2-74.

[redacted]

Modulation analysis is correct. In this section we will be looking at lines made by the chart recorder. Each signal received from the test coils will be transmitted to the ink filled needle. The signals cause the needle to move back and forth across the paper, leaving a tracing of the signal magnitude.

With the various signals that are generated at the coils by such properties as permeability, dimension, variations in hardness, stresses in the material and others, it is very hard to distinguish discontinuities such as cracks or holes in the specimen. Under normal conditions without modulation analysis, a chart recording with all of the signals from the specimen, will look like this.

Keep in mind that there is a required relative constant velocity between the test specimen and the probe or coil to produce an acceptable chart recording.

From the above chart record, can you identify which peaks are cracks, holes, dimension changes, or conductivity changes?

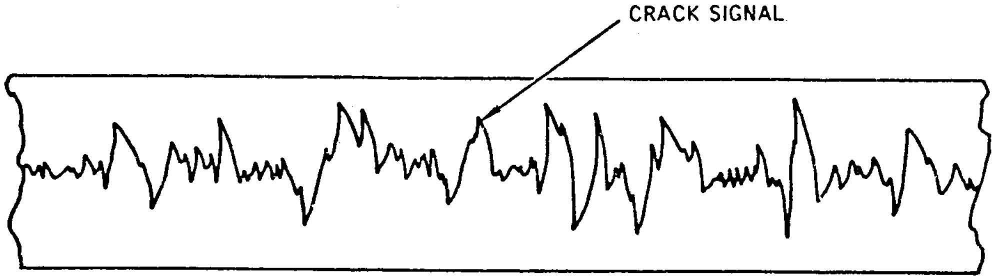
Yes . . . . Page 2-75
No . . . . Page 2-76

Yes? Try it ---. There is no characteristic of the peaks that will identify them or distinguish them one from another. Any one of them could be a discontinuity.

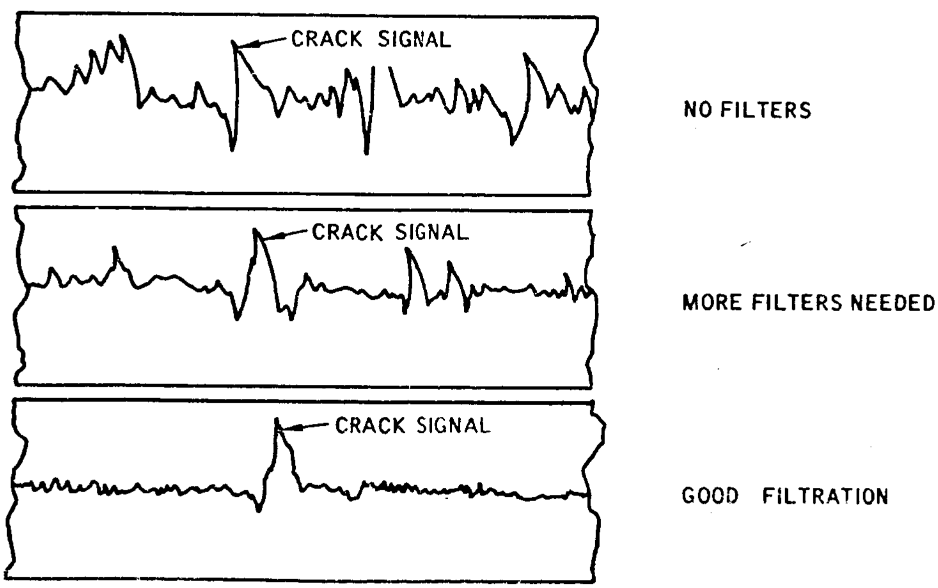
Return to page 2-74 and make another choice.

[redacted])

That's right! With all of those peaks, it would be impossible to decide which peak is which. Let's assume that only one of the peaks on the chart recorder paper was caused by a crack or discontinuity. The rest of the marks or peaks are caused by what we call noise.



This is very similar to the noise we get on a radio receiver. When we have noise on a radio it hides the sounds that we wish to hear. Our problem is to get rid of the other peaks or noise so we can see the signal caused by the discontinuity. So we place filters in the electronic circuits to filter out the noise and allow only those signals we want to come through. This is what is done in modulation analysis. By placing filters in the equipment we can eliminate the noise that hides the discontinuities.



Please turn to the next page for a short summary.

From page 2-76

SUMMARY OF CHAPTER 2

METHODS AND INDICATIONS

First — The first three methods of eddy current testing we studied were:

a. Impedance testing

b. Reactance testing

c. Feedback-controlled testing

Second — Impedance testing is a method of detecting discontinuities in a specimen. By measuring (and indicating on a meter) the magnitude of the changes in impedance at the coil a discontinuity in the specimen can be detected. The important thing to remember is that this method senses the magnitude of the changes of the coil impedance.

Third — Generally speaking, most discontinuities such as cracks, holes, inclusions, porosity, dents or unwanted changes will effect the coil impedance.

Fourth — A very important factor to remember is that the indication in impedance testing will not identify which property of the specimen caused the impedance change. It could be conductivity, dimension, or permeability.

Fifth — In reactance testing we monitor the frequency changes that take place when a discontinuity in the specimen is detected.

Sixth — The reactance of the coil changes when a discontinuity is detected. This reactance change will alter the oscillator frequency at the test coil.

Seventh — Neither impedance testing or reactance testing can distinguish between or separate the three main variables (conductivity, permeability, and dimension).

Eighth — The feedback-controlled testing method senses changes in the L/R ratio (inductance/resistance) caused by a heat loss in the coil.

From page 2-77

SUMMARY OF CHAPTER 2 (Cont)

Ninth The next three methods of eddy current testing are:

a. Vector point

b. Ellipse

c. Linear time-base

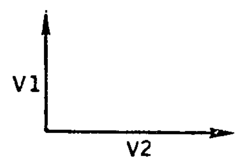
Tenth Information about the discontinuity can be increased with the use of the cathode ray tube as an indicator.

Eleventh The vector point method displays a point of light on the cathode ray tube.

Twelfth The shape and relative position of the display on the cathode ray tube gives valuable information about the discontinuity.

Thirteenth The vector point method will always display a point of light - never a waveform.

Fourteenth The vector point represents two voltages. One is applied to the vertical (V1) and the other is applied to the horizontal (V2).

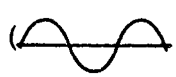


Fifteenth The conductivity variable is 90 degrees apart from the dimension and permeability variables.

Sixteenth If the conductivity variable is on the horizontal line, the dimension and permeability variable is on the vertical line.

Seventeenth Dimension and permeability changes cannot be separated. However, with the use of magnetic saturation, the permeability variable can be eliminated.

Eighteenth The phase shifter control can change the position of the display on the cathode ray tube.

Nineteenth In the ellipse method we have an ac signal () on the horizontal plates and the signal from the coil on the vertical plates.

From page 2-78

SUMMARY OF CHAPTER 2 (Cont)

Twentieth	The display on the CRT (ellipse method) is an inclined line for a dimension variation or an ellipse for a conductivity variation.
Twenty-first	The ellipse method will separate the conductivity, dimension and permeability variables.
Twenty-second	The signal on the horizontal plates of the CRT in the linear time-base method is a saw tooth () shaped signal.
Twenty-third	The BALANCE controls on the linear time-base equipment will smooth out or more evenly balance the two signals coming from the coils.
Twenty-fourth	The PHASE control of the linear time-base equipment will shift the signal left or right on the CRT.
Twenty-fifth	With the use of a transparent overlay, the waveform can be traced and compared to signals from other specimens.
Twenty-sixth	The slit technique is a specific use of the linear time-base method and uses the phase analysis principle of evaluation.
Twenty-seventh	Sorting is another valuable use of the linear time-base method.
Twenty-eighth	Because of the conductivity variation between metals of different alloys, it is possible to sort them with the eddy current - linear time-base equipment.
Twenty-ninth	Modulation analysis is designed to eliminate the noise or unwanted portion of the input and leave only the signal showing the discontinuity.
Thirtieth	Modulation analysis usually indicates its results on a chart recorder.

From page 2-79

1. Impedance testing indicates the magnitude of the ________________ changes in the coil.

7. cathode ray

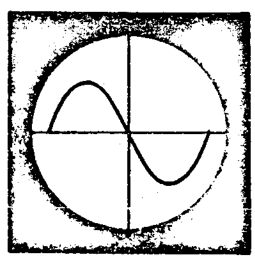
8. Which of the indicators below will give the most information about the specimen?
   1. Meter
   2. Cathode ray tube

14. straight line

15. Will the ellipse method of eddy current testing separate or distinguish between conductivity, and dimension and permeability?

    Yes _____ No _____

21. Left and right (horizontally)



22. Which of the three cathode ray tube (CRT) methods is illustrated?
    1. Linear time-base
    2. Vector point
    3. Ellipse

From page 2-80

1. impedance

2. Generally speaking, most discontinuities such as cracks, holes, inclusions, porosity, or dimension changes will change the test coil ________________.

8. Cathode ray tube

9. The vector point method will sometimes display a waveform on the CRT.

True _____ False _____

15. Yes

16. In the ellipse method a change in dimension will be indicated as . . .

. . . a slanted line

. . . an ellipse

22. Linear time-base

23. In the linear time-base technique, the waveform, because of a phase shift, will move . . .

. . . left or right

. . . up or down

From page 2-81

2. impedance

3. It ______ (is/is not) possible to distinguish between conductivity and dimension changes in impedance testing.

9. False

10. The conductivity variable is (in phase/out of phase) with the dimension and permeability variable.

16. a slanted line

17. In the ellipse testing method, a conductivity variable will display an ____________ on the cathode ray tube.

23. Left or right

24. The waveform <u>appears</u> to move (up or down/left or right) when viewing through the slit.

From page 2-82

3. is not

4. In reactance testing, indications are received when the coil reactance is changed by a change in the oscillator f__________.

10. out of phase

11. With the conductivity variable applied to the vertical component, a dimension change will move the vector point . . .

. . . horizontally

. . . vertically

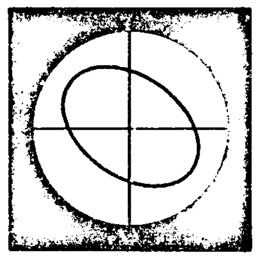
17. ellipse

18. An indication on the CRT like this would indicate

. . . a conductivity change

. . . a dimension change

. . . both.



24. up or down

25. Is it possible, when using the linear time-base method, to separate conductivity from the other variables?

Yes _____ No _____

4. frequency

5. The first three types of testing methods studied were:

   a. I__________

   b. R__________

   c. F__________-C__________

11. horizontally

12. With the use of magnetic saturation we can eliminate the __________ variable.

18. both

19. A saw tooth signal is placed on the horizontal plates of . . .

   . . . ellipse testing equipment

   . . . linear time-base testing equipment

   . . . vector point testing equipment

25. yes

26. Sorting is generally a function of which method?

   Ellipse

   Linear time-base

   Vector point

From page 2-84

5. Impedance
Reactance
Feedback-Controlled

6. A change in the L/R ratio (inductance/resistance) caused by the heat loss in the coil can be detected and displayed by the f__________ - c__________ testing method.

12. permeability

13. By adjusting the ________ shifter, we can position the display to various places on the CRT.

19. Linear time-base

20. The BALANCE control on linear time-base equipment is used to smooth out and balance the signal from the test coils.

True _____ False _____

26. linear time-base

27. Modulation analysis test system separates the noise or unwanted input from the signal that shows the discontinuity.

True _____ False _____

6. feedback-controlled

7. Vector point, ellipse, and linear time-base testing are usually displayed on a __________ __________ tube.

Return to page 2-80, frame 8.

13. PHASE

14. When the two specimens are identical, what kind of display will appear when using the ellipse method.

a. straight line
b. ac waveform
c. ellipse

Return to page 2-80, frame 15.

20. True

21. On the linear time-base equipment, the PHASE control will shift the waveform . . .

. . . up and down (vertically)

. . . left and right (horizontally)

Return to page 2-80, frame 22.

27. True

Turn to page 3-1 for the next chapter.

You should be convinced at this point that eddy current testing as a quality control system has an exceptionally broad range of capabilities. Besides its ability to detect discontinuities such as cracks, holes, dimensional changes, inclusions, etc., it can determine metal hardness, ultimate tensile strength, thickness and alloy.

In this chapter we will attempt to illuminate some of the uses of eddy current, the requirements of testing with eddy current, its capabilities, methods, and information vital to the application of this nondestructive testing system.

There are certain basic requirements for the testing system. These can be identified in three major areas.

- The item to be inspected
- A testing system
- Acceptance standards

SPECIMEN TO BE TESTED → TESTING SYSTEM → ACCEPTANCE STANDARDS

Into which of these three areas would the following be placed. . . cylinders
tubing
sheets
coatings

SPECIMEN TO BE TESTED . . . . Page 3-4

TESTING SYSTEM . . . . Page 3-2

ACCEPTANCE STANDARDS . . . . Page 3-3

From page 3-1

Your choice is wrong. ~~TESTING SYSTEM~~

cylinders,

tubing,

sheets, and

coatings. . . . . are SPECIMEN TO BE TESTED

Return to page 3-1 and try again.

From page 3-1

You goofed - you made the wrong selection.

~~ACCEPTANCE STANDARDS~~

cylinders,

tubing,

sheets, and

coatings. . . . . fall into this category. .

SPECIMEN TO BE TESTED

Turn to page 3-4.

[redacted])

From page 3-1

Good choice, cylinders,
tubing,
sheets, and
coatings. . . . . are

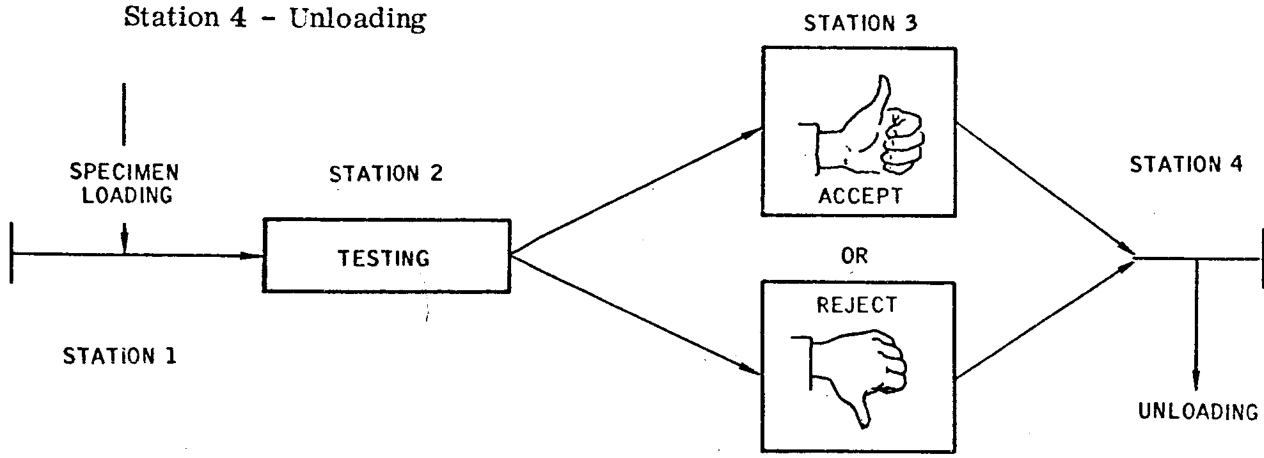
SPECIMEN TO BE TESTED

Later in this chapter we will discuss more specifically the tests made on this group of specimens.

TESTING SYSTEM

A complete testing system usually requires the following stations:

Station 1 - Loading
Station 2 - Testing
Station 3 - Accept or reject
Station 4 - Unloading



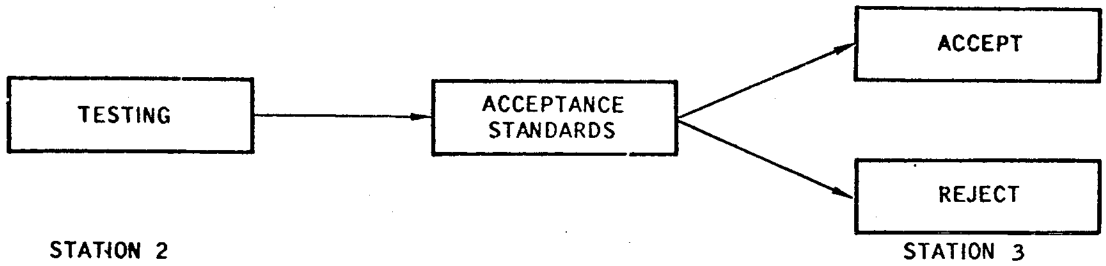
Where would you expect the **ACCEPTANCE STANDARDS** to go into effect?

Between Station 1 and 2 . . . . Page 3-5
Between Station 2 and 3 . . . . Page 3-6
Between Station 3 and 4 . . . . Page 3-7

From page 3-4

Sorry! You made the wrong choice.

The $\boxed{\text{ACCEPTANCE STANDARDS}}$ will be applied between stations 2 and 3.



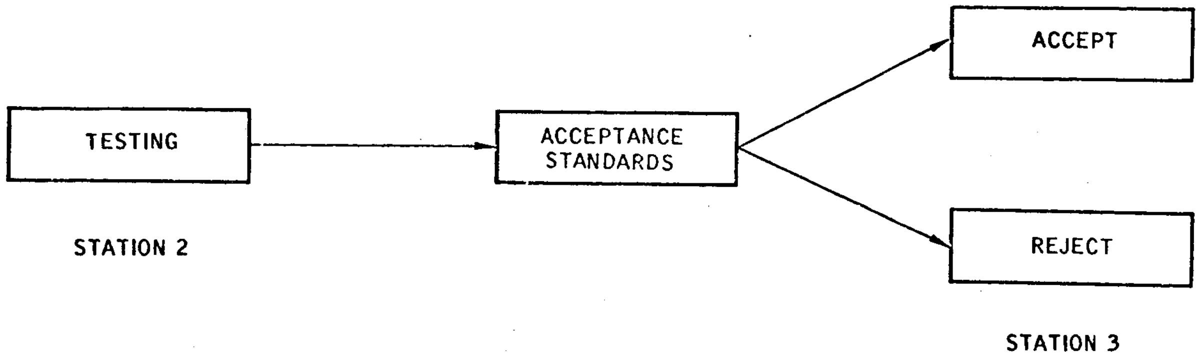
This can, of course, be done automatically (by the equipment) or manually by an experienced inspector.

Return to page 3-4 and choose again.

[redacted]

From page 3-4

Very good - the ACCEPTANCE STANDARDS will go into effect between stations 2 and 3.



This seems reasonable, don't you think?

After the test specimen has been tested, the STANDARDS OF ACCEPTANCE are applied to the information gathered and a decision to ACCEPT or REJECT is made, either automatically by equipment with acceptable limitations built in or by a qualified operator.

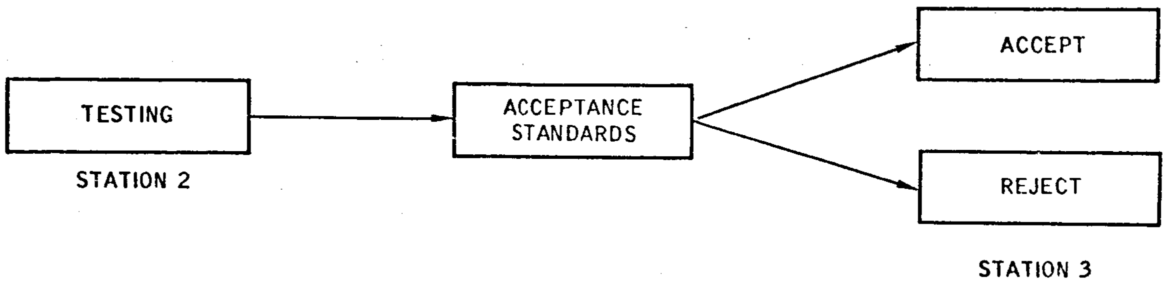
Let's have a look at the ACCEPTANCE STANDARDS. . turn to page 3-8.

[redacted]

Oops - Sorry! Wrong choice.

The **ACCEPTANCE STANDARDS** will take effect between - -

the **TESTING** (STATION 2) and the **ACCEPT** / **REJECT** (STATION 3)



Turn to page 3-6.

[redacted]

From page 3-6

Acceptance standards are a requirement of all eddy current testing. The inspector must know, or the equipment be able to detect, what is and what is not acceptable. To simplify this requirement, it is necessary that a standard specimen be chosen that is made of the same material as the test specimen. It must be of acceptable size, shape, alloy, etc. This specimen then becomes the standard and is identified and kept separate from the test specimens. The equipment is then set up to indicate any discontinuity in the test specimens forthcoming. Or, the standard specimen is used continuously as a comparison. When a test specimen is found that is not within the acceptable limits of the standard specimen, the equipment or the inspector will reject the specimen. The inspector shall, by application of his experience and judgment, determine the quality of the part being tested by comparison with the standard specimen.

There are two arrangements:

1. Absolute
2. Differential

With the use of the absolute coil arrangement, the standard specimen is used to set up the test equipment. When the equipment is adjusted or balanced to the standard specimen, the specimens to be tested are fed through the coil and evaluated.

When the differential arrangement is used, the standard specimen is placed in one coil and compared to the test specimen in the other coil.

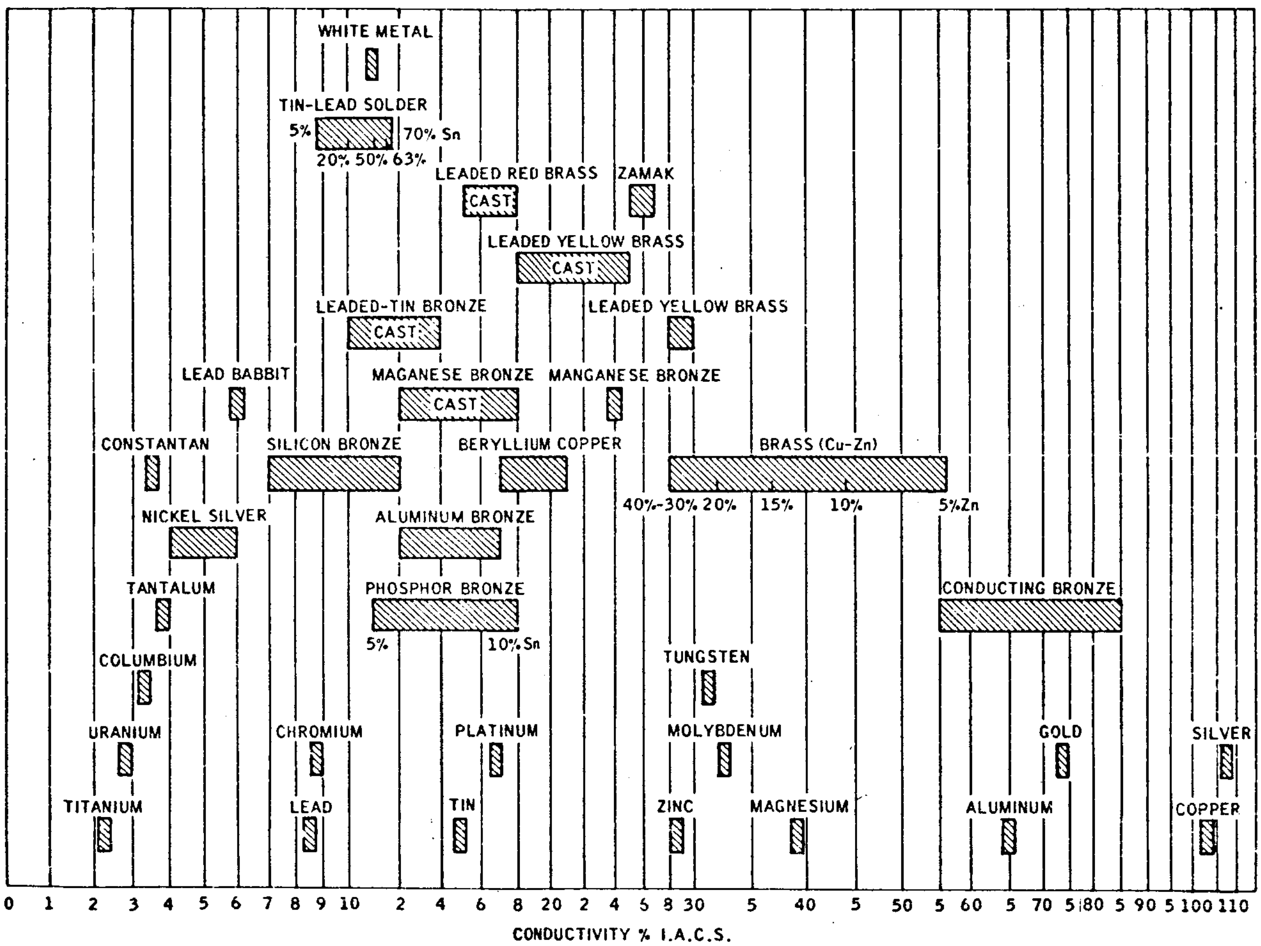
Turn to page 3-9.

[redacted])

Conductivity Testing

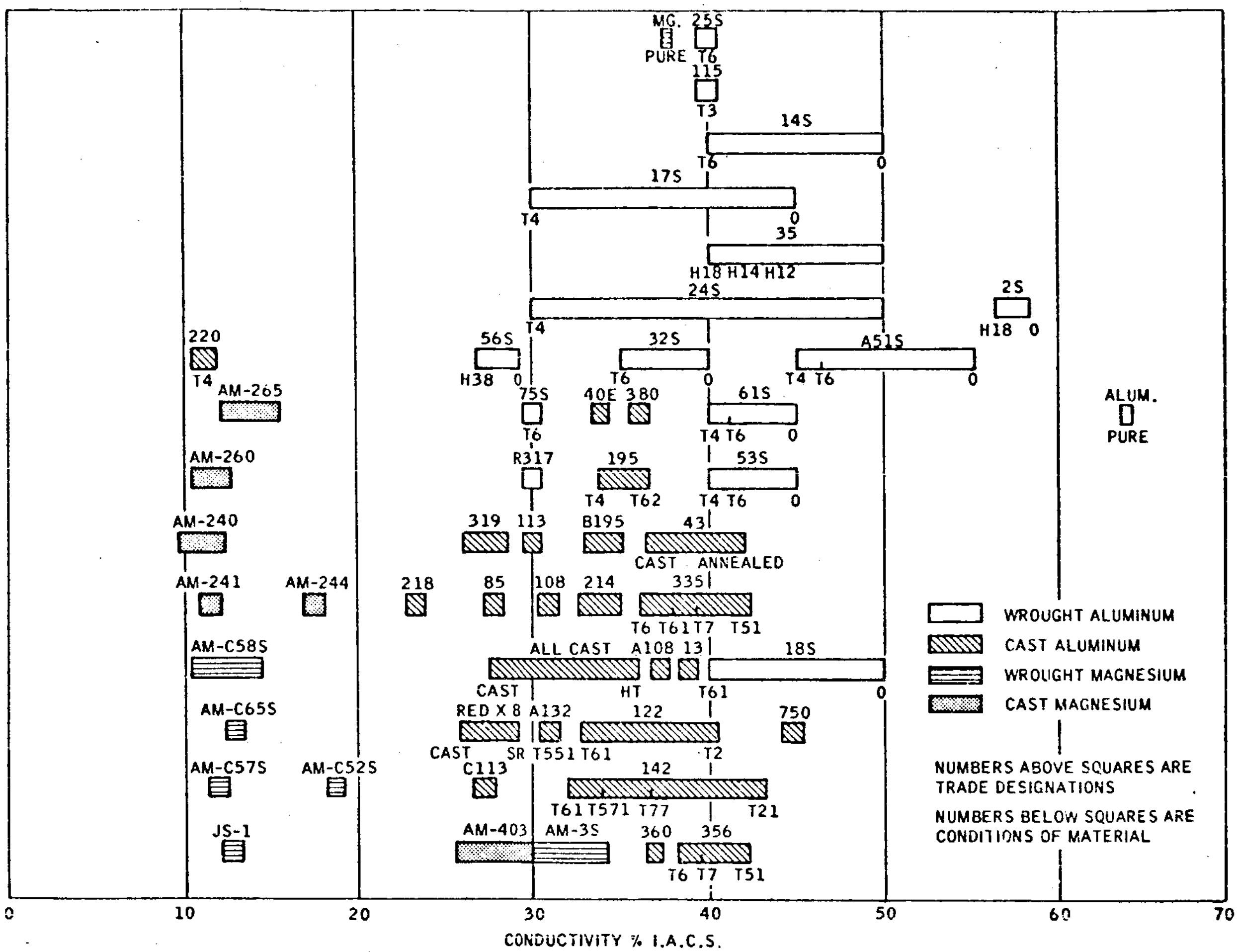
Conductivity, one of the three variables that we are concerned with in eddy current testing (conductivity - dimension - permeability), has become one of the major non-destructive testing techniques for the inspection of conducting metal products.

The conductivity of a metal is expressed as a percentage (%) and is based on the International Annealed Copper Standard (IACS) with a specific grade of high purity copper arbitrarily designated as 100% conductivity. All other metals can be identified according to this standard.



Turn to the next page.

[redacted])



Because of this characteristic it is possible to identify different metals by their conductivity. Actually it is more useful to identify the various alloys of base metals than to identify the base metals themselves. By using this method of identification we can sort specimens. In the event that many materials of similar shape and size but of different alloys become mixed together, it is very easy to sort these by the use of a conductivity tester. Besides alloy identification it is possible to detect variations in physical properties of metals such as hardness, aging, heat treatment, internal stress, etc. All of these physical properties will generally have an effect on metal conductivity.

Variations in the physical properties of a metal are best detected by. . .

conductivity testing . . . . Page 3-11

discontinuity testing . . . . Page 3-12

That is correct - Conductivity testing will detect variations in the physical properties of metals. Actually, even though we have separated conductivity testing from discontinuity testing, they are very much alike. Both methods test the conductivity of the specimen. But in one (conductivity testing), we are testing for physical properites of the specimen and in the other (discontinuity testing) we are looking for such things as cracks, holes, inclusions, or dimensional changes.

<u>Permeability Testing</u>

A not too common method of testing, permeability testing, is the ability of a material to accept a magnetic field. There are properties of metals that have a relatively greater effect on permeability than they do on conductivity. Generally speaking, chemical composition of a metal will have an effect on the magnetic permeability. Where grain size and orientation, internal stresses caused by cold working and case hardening are encountered, permeability testing can be very effective.

There are, however, certain advantages to working with conductivity changes rather than magnetic disturbances. In most cases the changes caused by magnetic disturbances are not important to the test. That is, these changes will have no effect on the serviceability of the part. For example, a long length of wire may have many changes in permeability along its length resulting from hardness changes or changes due to cold working. These magnetic or permeability variations can be overcome or eliminated if they become a problem to the test. By saturating the test specimen with a strong magnetic field, the permeability effect can be reduced to zero. This is done by means of a high amperage direct current.

Turn to page 3-13.

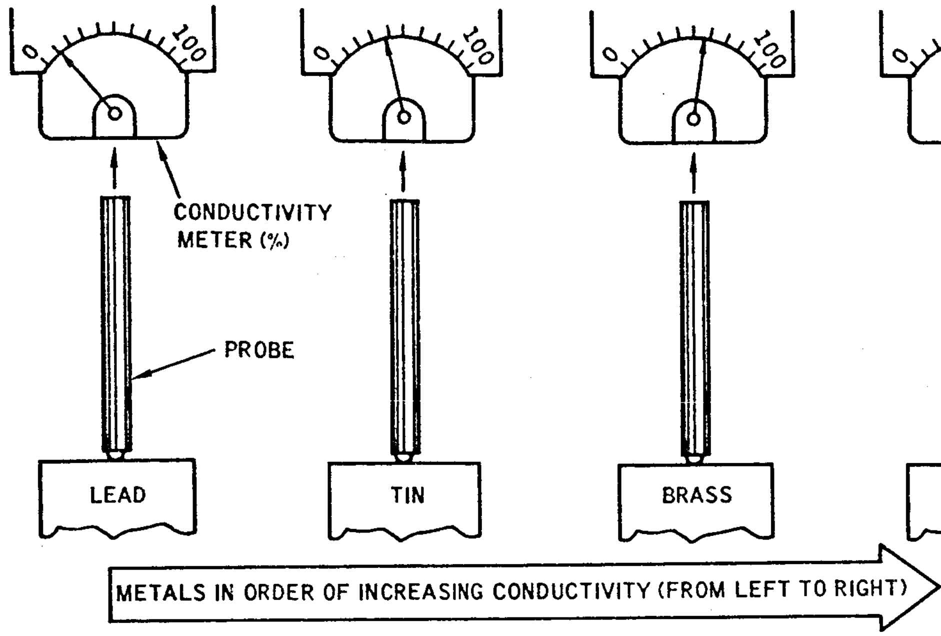
[redacted])

From page 3-10

That is incorrect. Conductivity testing is the best for the testing of metals with variations in their chemical properties. However, conductivity testing will also detect discontinuities of many various kinds.

Conductivity Testing	Discontinuity Testing
Sorting	Cracks
Hardness	Holes
Heat treatment	Porosity
Alloy	Dimension
Tensile strength	Inclusion
Carburization	Surface condition
Temperature	Soft spots

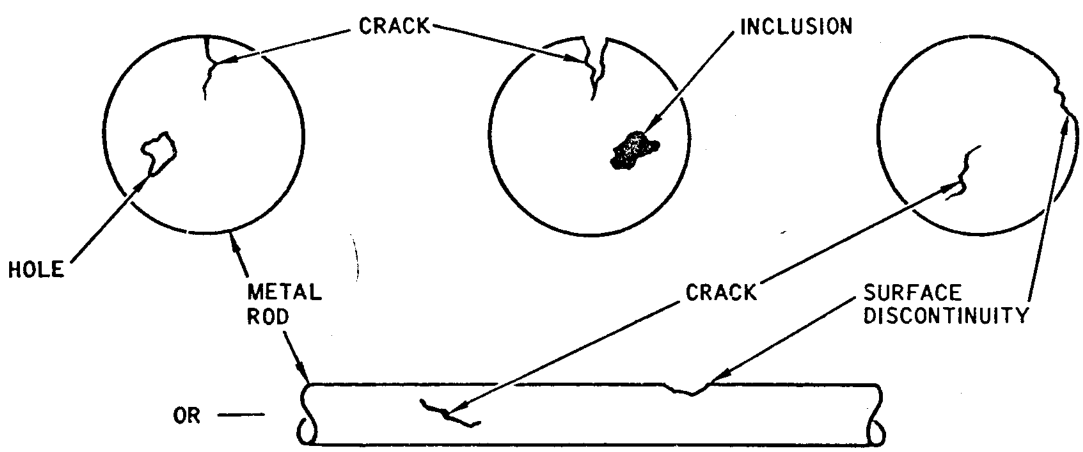
Turn to page 3-11.



RELATIVE INSTRUMENT READINGS WHEN PROBE IS APPLIED TO VARIOUS METALS

Discontinuity Testing

On equal footing (at least) with conductivity testing is discontinuity testing. Only now we are looking for things that may directly cause failure of metals. Such things as cracks in the metals, cracks that can run in any direction, be various widths and various depths.



Under which testing method would the following be classed: inclusion, hole, dent, scratch, lap, and seam.

Conductivity testing . . . . Page 3-14

Discontinuity testing . . . . Page 3-15

From page 3-13

That's incorrect. Conductivity testing generally includes such items as changes in alloy, heat treatment, hardness and tensile strength.

Discontinuity testing will include: cracks, inclusions, dents, scratches, seams, and laps.

Turn to page 3-15.

[redacted])

Very good! The items listed fall into the discontinuity testing area.

Remember the two most prominent testing methods in eddy current are:

- Conductivity testing
- Discontinuity testing

<u>Thickness Testing</u>

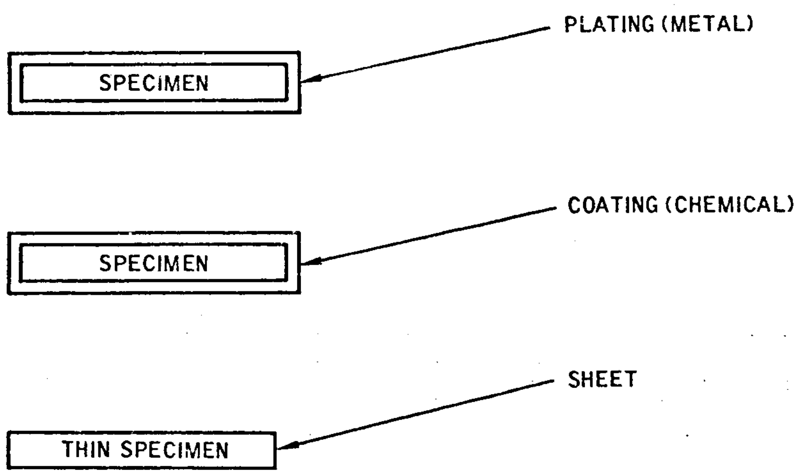
Another very useful application of eddy current testing is that of thickness testing. With the proper use and arrangement of coils it is possible to measure thickness of a great variety of items. Generally this testing system is restricted to specimens 1/8th inch or less. The most common uses of this system are:

- Coating thickness
- Plating thickness
- Sheet thickness

A painted surface would fall into which of the three listed above:

Coating thickness . . . . Page 3-18
Plating thickness . . . . Page 3-16
Sheet thickness . . . . Page 3-17

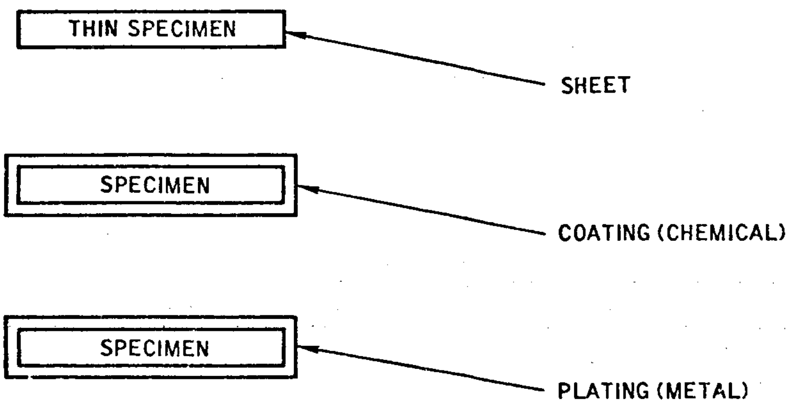
You chose plating thickness but that is not correct. The paint that was mentioned in the question is not plating, it is coating. Now that wasn't such a bad mistake. Actually plating as we use it here would be a metal cover or coating such as a chromium plated part or like your gold plated wrist watch. A coating would be a cover or cladding like paint or varnish, wax or other chemical.



Thus paint would be a coating.

Turn to page 3-18.

Your choice was "Sheet thickness" and that is wrong. Paint is not a sheet thickness. The correct answer is coating thickness. Let's explain further. When we speak of sheet thickness testing we are speaking of thickness of very thin sheets of metal like aluminum foil or tin that containers are made from. Thickness of metal up to about 1/8th inch can be checked or gauged. Paint then would be considered a coating as would varnish, plastic or other chemicals.



Turn to page 3-18.

From page 3-15

Very good! Again you have made the correct choice. Paint is a coating, it is not a sheet or a plating.

Now let's take a little closer look at these three methods of thickness testing.

- COATING
- PLATING
- SHEET

Within recent years, eddy current techniques have found widespread use in the application of measuring the thickness of coatings. Such applications take advantage of the sensitive relationship between non-conductive coatings and conductive base metal. Thickness of coatings can be determined up to a few thousands of an inch with 2 to 3 percent accuracy. For measuring coating thicknesses, the "gap" or coupling between the coil and the base metal is used as a measure. It is also used, when clear coatings are used, to determine which side of the base metal is coated.

Measuring the thickness of a thin layer of copper on the surface of a one inch aluminum plate would not be. . . .

. . . plating thickness testing . . . . Page 3-19

. . . coating thickness testing . . . . Page 3-20

From page 3-18

Better read that question again "Measuring the thickness of a thin layer of copper on the surface of a one inch aluminum plate would not be. . "

This would NOT be coating thickness testing.

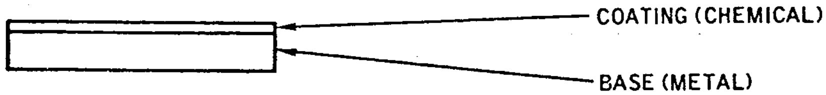
You made the wrong choice.

Return to page 3-18 and try again.

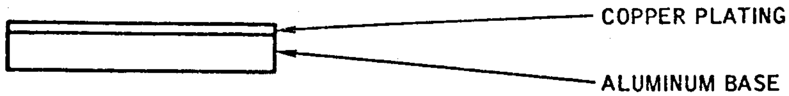
That's right! It would not be coating thickness testing, it is plating thickness testing because the copper is a thin metal layer, not a coating.

There are a number of combinations or situations where thickness testing can be applied. These are:

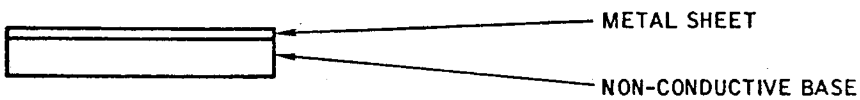
A CHEMICAL COATING ON A METAL BASE . . .



A METAL PLATING ON A DIFFERENT TYPE OF METAL BASE . . .



A METAL SHEET ON A NON-CONDUCTIVE BASE . . .



Which of the three below listed arrangements could not be used in eddy current testing:

CONDUCTIVE / NON-CONDUCTIVE	. . . . Page 3-21
NON-CONDUCTIVE / NON-CONDUCTIVE	. . . . Page 3-22
CONDUCTIVE / CONDUCTIVE	. . . . Page 3-23

From page 3-20

Incorrect choice:

CONDUCTIVE
NON-CONDUCTIVE

is an arrangement that <u>can</u> be used in eddy current testing. The only one of the three that <u>cannot</u> be used is

NON-CONDUCTIVE
NON-CONDUCTIVE

The reason for this is, if you recall from earlier studies, that we must have conductive materials for eddy current testing. At least one of the layers (when testing for coating or plating thickness) must be conductive.

Turn to page 3-22.

[redacted])

From page 3-20

NON-CONDUCTIVE
NON-CONDUCTIVE

Right! This arrangement will not work with eddy current testing because at least one of the layers must be able to conduct eddy currents. Both of the others can be tested by eddy current.

Remember. . . . .

CONDUCTIVE
NON-CONDUCTIVE

NON-CONDUCTIVE
CONDUCTIVE

CONDUCTIVE
CONDUCTIVE

. . These three arrangements can be tested for thickness by eddy current methods.

Of course there is one more that was mentioned briefly – that being: A single sheet of conductive material, with no coating or plating on either side, can also be tested with eddy current methods. Keep in mind here that eddy current testing is good only on these sheets or coatings of less than about 1/8th inch thickness.

The principle used in thickness testing is "Lift-off". That is to say, when checking the thickness of a non-conductive coating, the eddy current test equipment actually measures the distance between the base metal and the probe. This, of course, is the "lift-off" distance.

The most important principle of thickness testing is. . . .

. . depth of penetration . . . . Page 3-24
. . lift-off . . . . Page 3-25

Wrong choice! $\boxed{\begin{array}{c}\text{NON-CONDUCTIVE}\\ \hline \text{NON-CONDUCTIVE}\end{array}}$ is the combination that cannot be used in eddy current testing. Either of the other two can be used with either plating or coating thickness testing. If you recall from previous study, to test with eddy current there must be a conductive material for the eddy current to flow. Thus it is necessary for one of the two or both to be conductive.

Return to page 3-20 and make another selection.

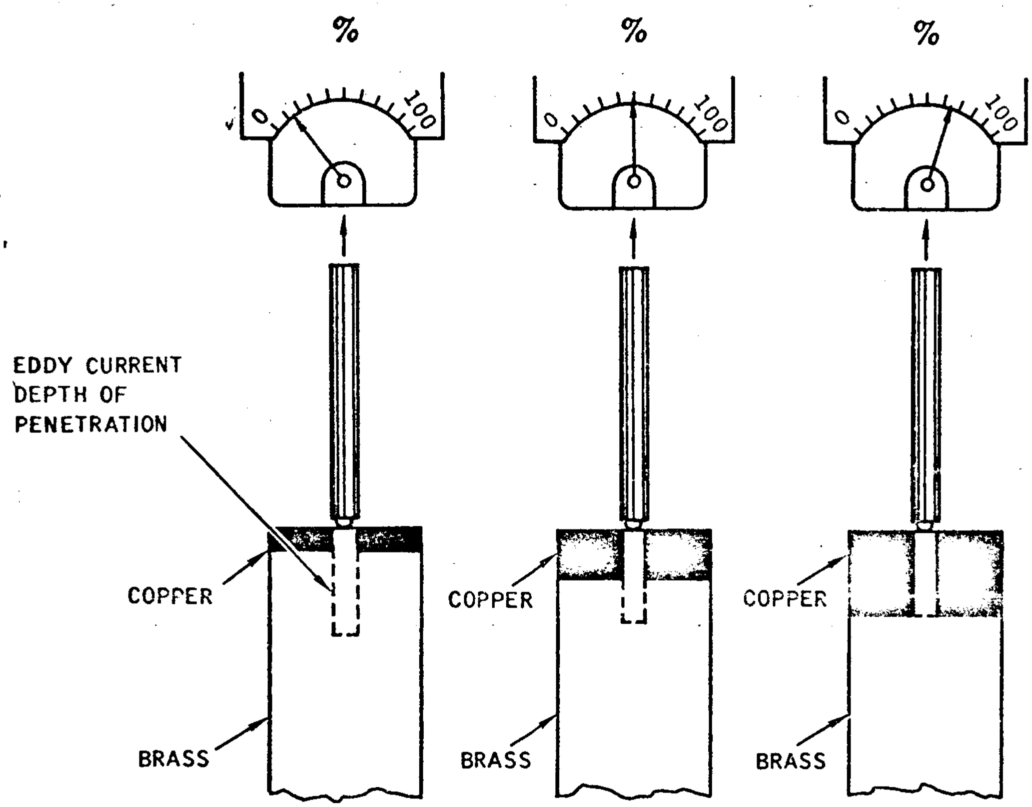
Not quite right. "Lift-off" is the important principle of thickness measurement. However, the depth of penetration is also an important consideration.

Turn to page 3-25 and see why.

From page 3-22

That is correct! "Lift-off" is the most important. However, the depth of penetration must be considered when making such tests. As you know, an increase in conductivity will decrease the depth of penetration. Therefore as shown below:

As the thickness of the copper plating increases, the conductivity increases and the depth of penetration decreases.



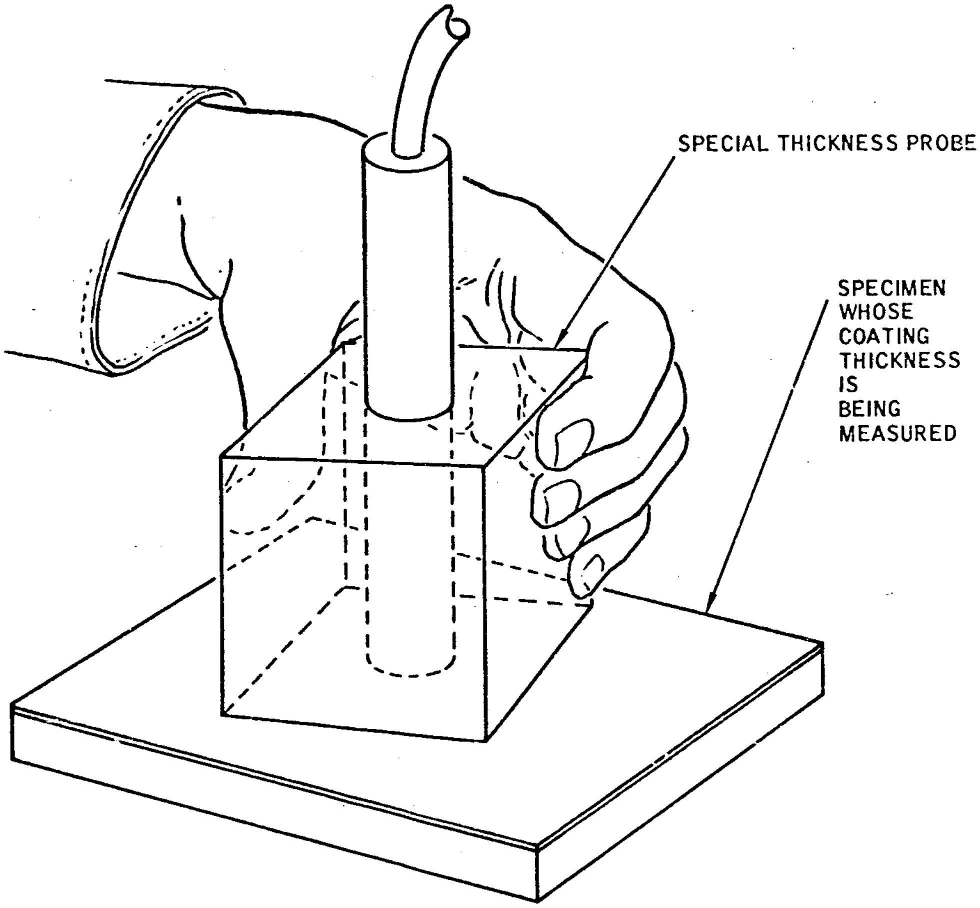
RELATIVE INSTRUMENT READINGS FOR VARIOUS
THICKNESS OF COPPER PLATE ON BRASS BASE

With the use of known thickness standards, and knowing the conductivity of both metals, we can measure the thickness of the coating or plating on a specimen.

Turn to the next page.

From page 3-25

The illustration below gives some idea of the thickness probe and its use. The large block gives a more even surface and remains flat against the specimen when the probe is moved from place to place.



Another thickness measurement application is that of tube wall thickness and rod or wire diameter. In both cases the standard thickness probe is replaced by an encircling coil. A procedure similar to the plating thickness measurement is used when checking tube wall thickness. A procedure similar to the coating thickness measurement is used for the rod and wire diameter measurement.

Can any type coil be used for any test, or must the coil be selected according to the test to be performed?

Any type coil . . . . Page 3-27

Careful selection of coil . . . . Page 3-28

Now you should know better than that. Maybe you read the question wrong.

It is necessary to use certain coils for specific jobs. For example, you would not use an encircling coil for thickness testing of aluminum foil. There is a correct coil for each type of eddy current test.

Turn to page 3-28.

From page 3-26

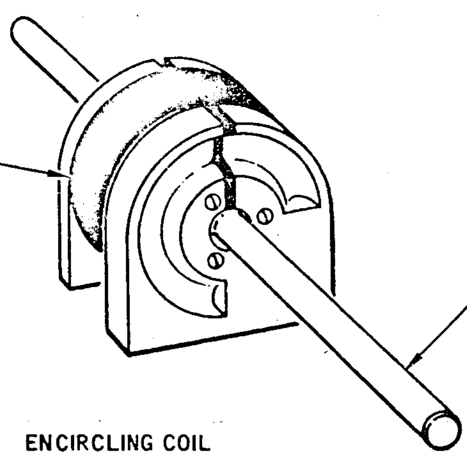
Certainly! The specimen to be checked will determine the type of coil that should be used. The same kind of coil cannot be used to check both cylinders and metal sheets. Let's have a look.

Choice of Coils and Probes

The sensing head of eddy current equipment is the test coil. Made up of one or more windings and designed in many different shapes and sizes, the test coil serves as both a transmitter and receiver for the eddy current field. Basically, test coils fall into three categories:

- Encircling Coil
- Inside Coil
- Surface Coil (Probe)

The encircling coils are wound on bobbins of different sizes so that a variety of specimen sizes can be passed through them. That is, large tubing would be tested by a coil very close to the same diameter as the tubing being tested. Wire, however, would require a very small coil just large enough to allow the wire to pass through.



ENCIRCLING COIL

If you wish to test the inside of a large tube (2 inch diameter) which coil would be best?

Encircling coil . . . . Page 3-29
Inside coil . . . . Page 3-30

Encircling coil would not be best. It could be used in some circumstances but generally the inside coil would do a better job. The test of the inside of a tube, depending on its length, can be performed with an inside coil or a small probe coil attached to a long rod.

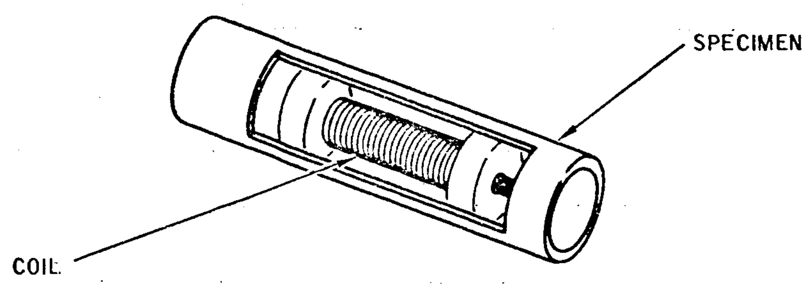
Turn to page 3-30.

[redacted])

From page 3-28

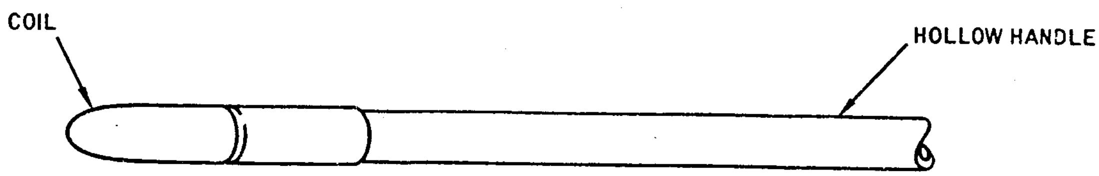
Sure! An inside coil would be the right coil for the test of the inner surface of a tube.

Inside coils are wound on bobbins also but such that they can be moved through a tube with ease.



INSIDE COIL

The bobbin is constructed of a special self lubricating material that will move easily through the tube. This inside type coil can also be attached to the end of a long hollow handle or tube as the illustration below shows. This coil can be inserted into the tube in a similar manner.



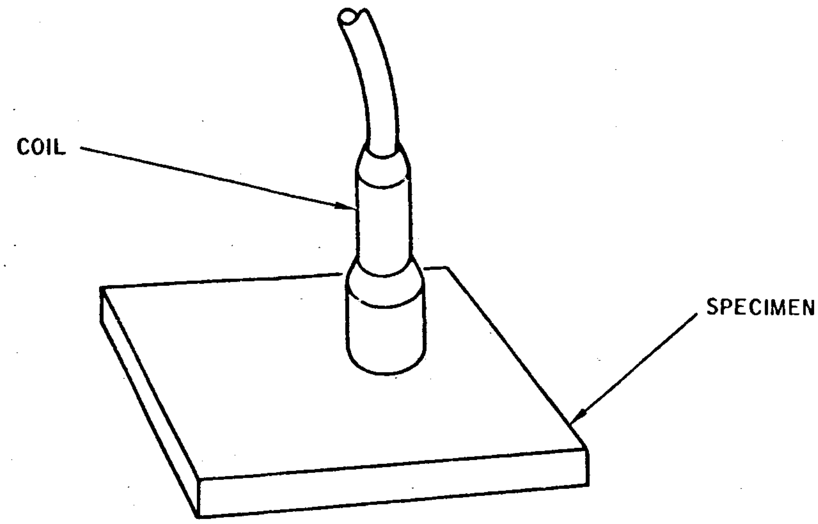
Which kind of probe would be best for testing conductivity of a flat sheet of metal?

Inside coil . . . . Page 3-31
Surface coil . . . . Page 3-32

[redacted]

Nope! To check a flat metal sheet the surface coil is the correct coil for the task.

See below illustration:

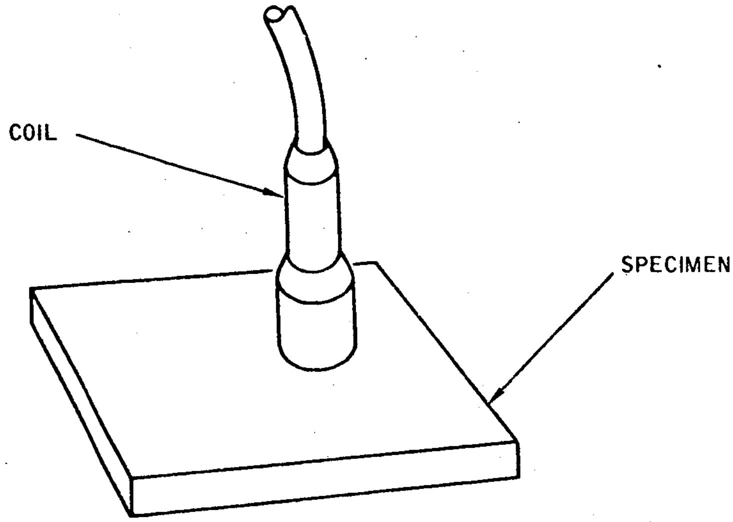


SURFACE COIL

Turn to page 3-32.

From page 3-30

Good for you! The surface coil is correct.



SURFACE COIL

Probably the most used of the various types of coils, the surface coil can be used on most specimens. The most common uses, of course, are for conductivity, crack location, and sorting. Instead of surrounding (encircling) the article or being inserted inside of it, surface coils are placed against the article and are most commonly used to scan flat articles or miscellaneous shapes. When necessary, the surface coil may be used on round stock such as tubing to detect or more accurately locate discontinuities that are difficult to detect and pinpoint with other types of coils.

There are many variations in coil design. Particularly those designed with special applications in mind. These will appear occasionally here and there but it is not necessary that they be discussed here.

Turn to the next page.

From page 3-32

Certain requirements must be met when preparing for eddy current tests. In various areas of application, the following should be considered:

1. A coil system designed for conductivity measurements should not be used for discontinuity detection.
2. When testing for small discontinuities, the coil size should also be very small.
3. When checking conductivity, the coil size should be relatively large to minimize the effect of any discontinuity.
4. When using an encircling coil or inside coil, the specimen feed rollers must be adjusted such that the horizontal and vertical position of the specimen will be centered in the coil and such that the specimen will pass through the system smoothly, without bouncing. Shocks may give false indications.
5. The specimen speed must be uniform through the coil.

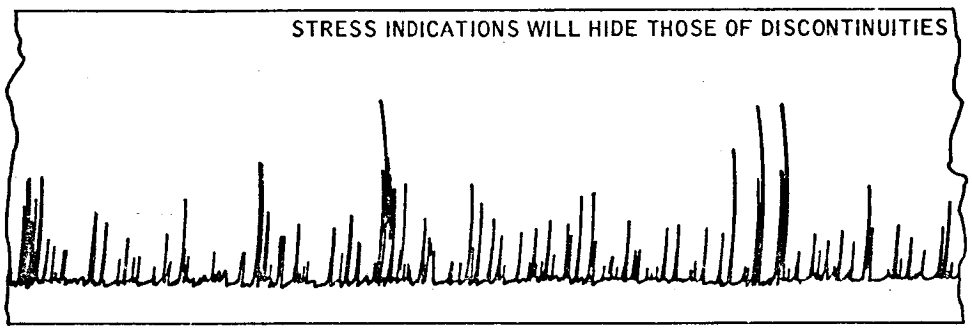
COIL	ADVANTAGES	LIMITATIONS
ENCIRCLING COIL	EVALUATES ENTIRE CIRCUMFERENCE AT ONE TIME HIGH SPEED NO WEAR PROBLEMS	WILL NOT IDENTIFY POINT ON CIRCUMFERENCE CONTAINING DISCONTINUITY SENSITIVE TO DIMENSION CHANGE
INSIDE COIL	EVALUATES INSIDE OF TUBES VERY GOOD SPEED EXCELLENT FOR BOLT HOLE TESTING	PROBE WEAR LIFT-OFF PROBLEM
SURFACE COIL (PROBE)	FAST TESTING OF LOCALIZED ZONE CRACK DETECTION, CRACK MEASUREMENT, SORTING	LIFT-OFF PROBLEM PROBE WEAR SPEED OF TEST

Turn to page 3-34.

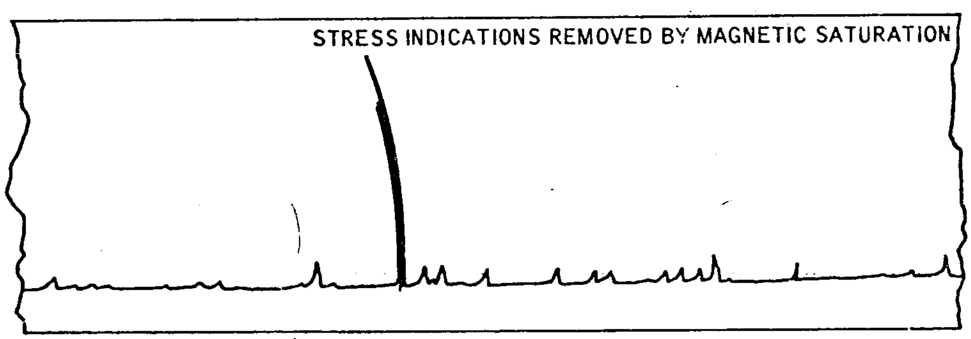
From page 3-33

Magnetic Saturation

When tests are being made of metals that are subject to magnetic forces or are considered ferromagnetic, the applied stresses in the metals will have a definite effect on the permeability or magnetic properties of the specimen. These applied stresses within the metals will then, because of their effect on magnetic permeability, indirectly affect the test responses. In some instances these applied stresses in the specimen will have greater effect on the test instrument than the discontinuity or other variables that may appear in the specimen. The illustration below shows how stresses in a magnetic material can hide discontinuities that may be present in the specimen.



It is possible to eliminate these permeability or magnetic effects with the use of a simple "Saturation Coil". A direct current (dc) is applied to a coil that surrounds the test specimen. This coil will magnetically saturate the specimen such that the permeability variables completely disappear.



When the test is complete, the magnetic saturation is removed from the specimen. Which of the three variables are most concerned with magnetic saturation?

Conductivity . . . . Page 3-35

Dimension . . . . Page 3-37

Permeability. . . . . Page 3-36

Wrong choice!. Although conductivity may be slightly effected by internal stresses in a metal, permeability is the variable that will be noticeably changed or effected. Also magnetic saturation will have no effect on the conductivity of the specimen, but it will completely eliminate the permeability effect.

Return to page 3-34 and make another choice.

From page 3-34

Well done! Permeability and magnetic saturation is our concern here. With the use of saturation, the magnetic (permeability) properties of the specimen are essentially eliminated for the duration of the test. Magnetic saturation is also a good way in which we can separate the conductivity, dimension and permeability variables.

Earlier in this volume, we studied some of the various methods of testing. The application of these methods can be very wide spread - for example:

The impedance analysis method can be used to measure diameter and thickness of coatings and plating. It can be used to detect discontinuities, and it can be used to sort various alloys of metals.

The phase analysis method, basically of course, detects variations caused by shift in phase. This phase change gives information that reveals various changes in the specimen under test. Changes in conductivity, the presence of discontinuities, permeability variations, depth of discontinuities are revealed, dimensional changes, and thickness. The phase analysis method gives more intelligent and meaningful information than impedance testing.

Turn to page 3-38.

Poor choice! Dimension and magnetic saturation have no relationship with each other. Magnetic saturation eliminates the effect magnetic properties display when a test is being conducted.

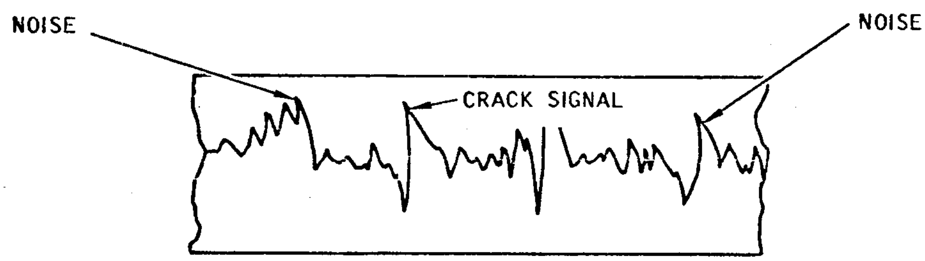
Return to page 3-34 and make another selection.

From page 3-36

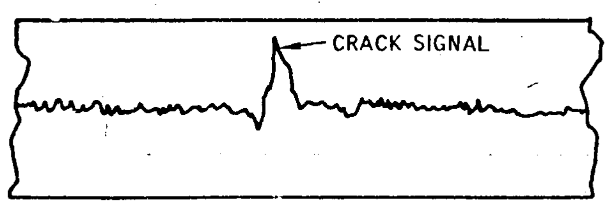
Modulation Analysis

Modulation analysis, possibly the most revealing method for a well qualified inspector, is widely used in eddy current testing. The automatic scanning of a metal specimen is very successfully carried out with the test coil voltage being frequency modulated by the variations in the test specimen. It has been found that discontinuities such as cracks, seams, holes, and inclusions will produce relatively high modulating frequencies. Stress and dimension variations produce intermediate frequencies while heat treatment and temperature variations produce low frequencies.

With the use of adjustable filters it is possible to reject certain of these modulating frequencies and pass only those that are desired. This method, often with reference to the signal/noise ratio, will eliminate the noise (unwanted frequencies) leaving only the signal (variables of interest).



BEFORE MODULATION ANALYSIS (FILTERING)



AFTER MODULATION ANALYSIS (FILTERING)

Turn to page 3-39.

[redacted])

Test capabilities of the eddy current methods are generally very good, that is of course, depending on the test required. Conducitivity testing can be done on any conducting metal. Tests relating to specimen thickness can be performed where specimen is less than 1/8th inch thick. It can be seen that the shape of the test object must be considered. Some of the common shapes that can be tested by eddy current are:

- Cylinders
- Tubing
- Sheets

Cylinders of course include a number of items such as wire, rods, and bars. These are all cylindrical in shape and so are usually tested with an encircling coil. Some items that can be tested for in cylinders are:

Cracks - surface cracks, inside cracks, laps, seams.

Conductivity - alloy composition, sorting, heat treatment, hardness, aging, and fatigue.

Dimension - Diameter, wear, shape, coating and plating thickness.

What do you think would best describe the difference between a cylinder and a tube?

Cylinder is solid - tube is hollow . . . . Page 3-40

Cylinder is square - tube is round . . . . Page 3-41

Cylinder is long - tube is short . . . . Page 3-42

Very good! The cylinder is solid, and the tube is hollow.

The hollow tube presents some slightly different problems than the cylinder. The hollow tube can be checked two ways. That is, from the outside (encircling coil) or from the inside (inside coil). Here again there are various tests that can be performed.

Cracks - surface cracks (inside or out), welds, seams, or laps.

Conductivity - alloy composition, heat treatment, hardness, and fatigue.

Dimension - diameter, eccentricity, wall thickness, coating and plating thickness.

An experienced inspector with proper equipment can separately identify a dent, corrosion, outside crack, inside crack, diameter change or a hole in the tube.

Which type coil would be most generally used to sort metal sheets by alloy composition.

Encircling. . . . . Page 3-43

Inside. . . . . Page 3-45

Surface. . . . . Page 3-44

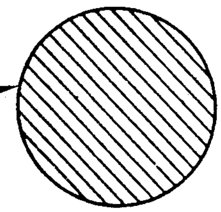
Sorry, wrong answer. A cylinder cannot be square and still be a cylinder. However, there are encircling coils that do check square bars but these coils are square in shape rather than round.

Return to page 3-39 and try again.

From page 3-39

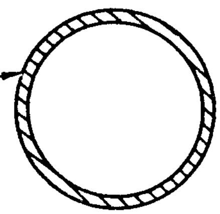
Not quite right! The length has nothing to do with whether it is a cylinder or a tube. Its cross sectional dimension determines this. A cylinder looks like this,

CROSS-SECTION OF A CYLINDER



a tube looks like this.

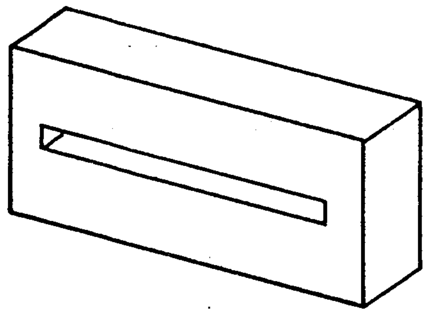
CROSS-SECTION OF A TUBE



Return to page 3-39 and make another choice.

From page 3-40

Wrong choice! The surface coil would be best to use on a sheet of metal. We are sure you can't imagine using an encircling coil on a large sheet of metal. There are however coils (See Illustration Below) that are designed to test small sheets. But they are specially designed for individual cases.



Turn to page 3-44.

That is right! The surface coil is the correct coil to use when testing a metal sheet. Unless of course the sheet is small and there are enough to be tested to require a special coil. There are coils specially designed for a particular shape if the volume of test objects make it economical.

Tests that can be performed on sheets are:

Cracks - surface or internal cracks, welds, seams, or laps.

Conductivity - alloy composition, heat treatment, hardness, and fatigue.

Dimension - sheet thickness, coating and plating thickness.

There are some other very important considerations that should be discussed relative to eddy current testing. We have mentioned these before in passing but now should get into a little more detail.

- Lift-Off
- Choice of Frequency
- Test Speeds

Eddy current discontinuity detection requires relatively close spacing between the probe and the test surface. This spacing is called lift-off when reference is made to surface testing. It is also referred to as fill factor in the use of encircling coils. To group or combine them into one term is often done and is referred to as coupling.

Do you suppose that the condition of the surface of the specimen will have any effect on the lift-off adjustment.

Yes . . . . Page 3-46

No . . . . Page 3-47

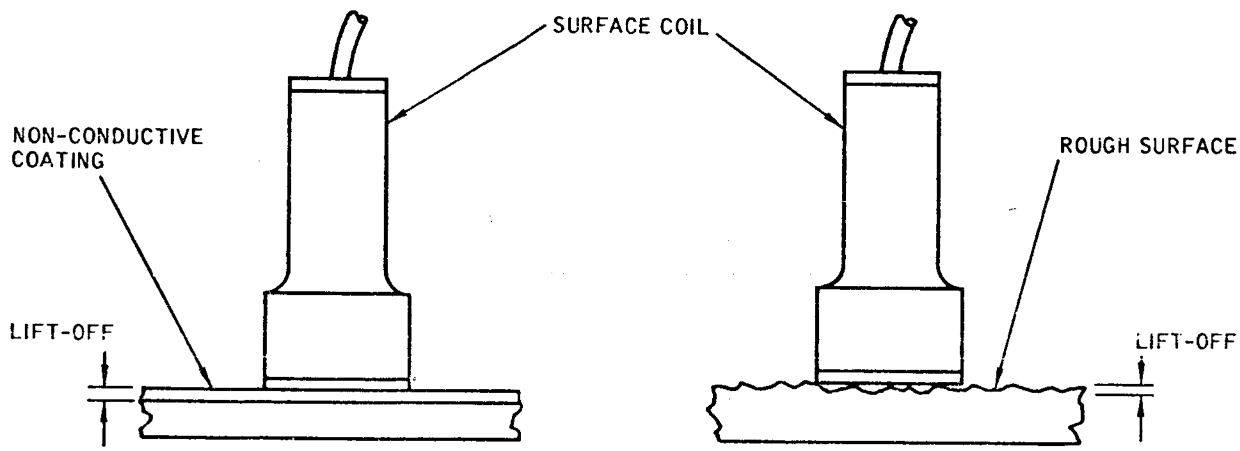
Inside coil is very wrong! There is no inside of a metal sheet that an inside coil could go into. You must be thinking of something else. The correct answer is the surface coil.

Turn to page 3-44.

From page 3-44

Very good! That is the right answer. The surface condition of a metal specimen does have an effect on the lift-off. An increase in surface roughness will effectively increase the lift-off.

It is the lift-off effect that is actually being used when coating thickness is being measured. If the coating is non-conductive, such as paint, then the test instrument indicates the paint thickness by showing the distance between the coil and the metal base. By adjusting lift-off, a rough surface can be by-passed and the specimen just below the surface can be tested.



Does the term fill factor have any relationship to lift-off?

No . . . . Page 3-49

Yes . . . . Page 3-48

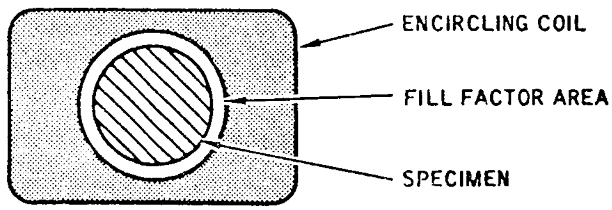
[redacted])

From page 3-44

No - That's the wrong answer. The surface condition of a metal specimen does have an effect on the lift-off. An increase in surface roughness will effectively increase the lift-off.

Turn to page 3-46.

Right! The fill factor and lift-off are related. They are both part of the magnetic coupling between the coil and the specimen. They are both very important. In actual test situations it is easily noted that any change in lift-off or fill factor will give noticeable indication on the equipment indicator. The fill factor is used most to describe the area between the inside diameter of the encircling coil and the outside diameter of the specimen passing through the coil.



As you can see, a small change in the diameter of the specimen can give quite a large change in fill factor area. Another important point that should be mentioned here is that when setting up the equipment for the test, great care should be taken in the adjustment of the feed rollers and guides. Feed rollers and guides ensure that the specimen travels through the coil at its center such that the space between the specimen and the coil is uniform all around the specimen.

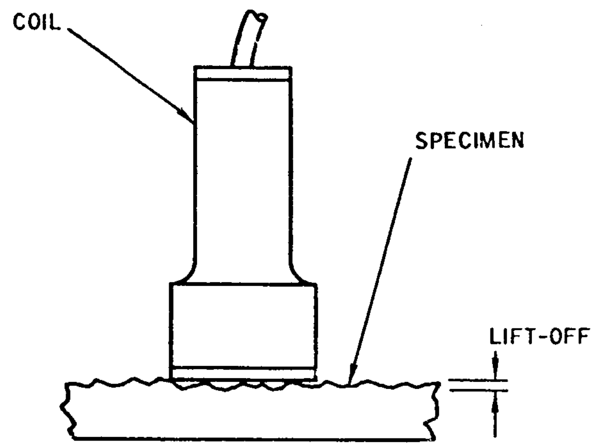
The fill factor is the ratio of the coil diameter squared to the specimen diameter squared. The closer this ratio is to "1" the better the fill factor.

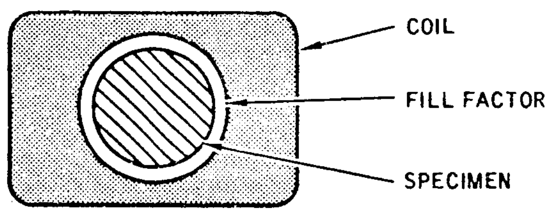
Is the ratio of the coil diameter squared to the specimen diameter squared a function of the . . .

. . . . fill factor . . . . Page 3-50

. . . . Lift-off . . . . Page 3-51

Wrong! The fill factor is related to lift-off. In both cases they are coupling. Lift-off is the distance between the coil and the specimen. Fill factor is the area between the coil and the specimen.





Turn to page 3-48.

[redacted])

From page 3-48

Excellent! A good choice. The fill factor is a ratio of the coil diameter to the specimen diameter squared and the nearer to "1" this ratio becomes, the better.

$$\text{Fill factor} = \left(\frac{\text{Coil Diameter}}{\text{Specimen Diameter}}\right)^2$$

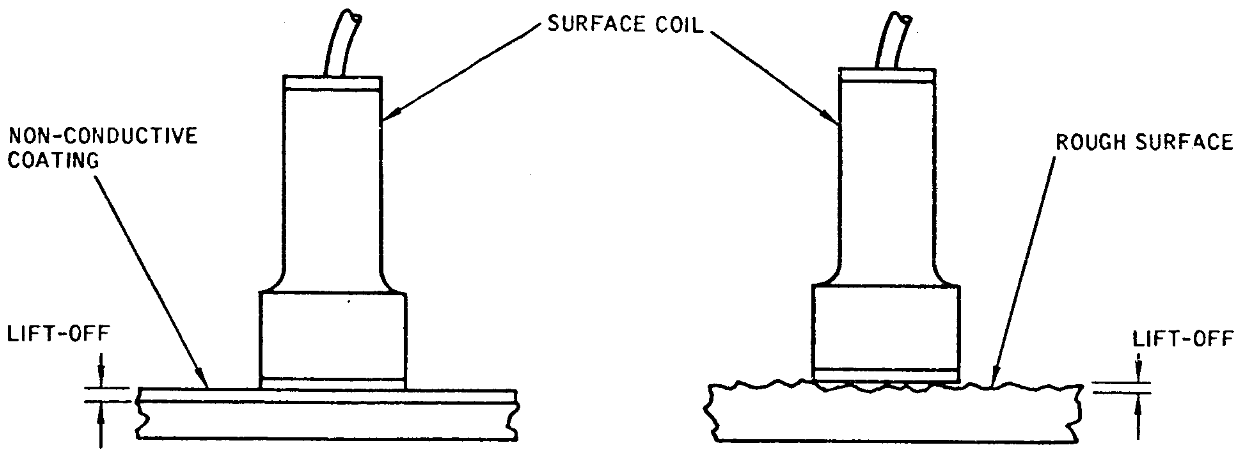
In eddy current testing the movement of the coil or the test specimen is often a very essential part of the test. Where a surface coil is used on sheet metal, the coil should be moved, uniformly if possible, across the surface of the sheet of metal being tested. When the specimen is a cylinder or tube, it can be moved through the coil at speeds of from 100 to 1000 feet per minute. If during the tests, the speed is held constant and free from irregularities, good results can be recorded.

The direction of movements in many types of test is important also. For best results, when checking for cracks, seams, welds, or discontinuities that have length, the relative motion should be transverse (across) the longest axis of the discontinuity. If checking discontinuities that have no specific length or shape, the relative motion is unimportant.

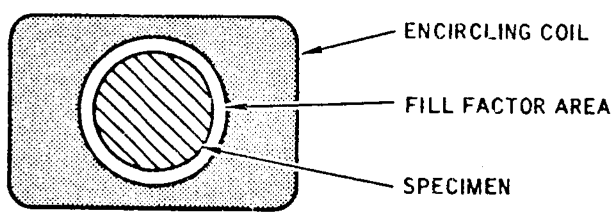
Under which circumstance is motion unimportant?

Checking tubing for cracks . . . . Page 3-52
Sorting bolts for alloy composition . . . . Page 3-53

Incorrect! The correct answer is fill factor. If you recall a few pages back, the lift-off is described as the distance between the coil and the specimen and is shown like this:



The fill factor is the area between the coil and the test specimen:



Turn to page 3-50.

[redacted]

No! You made the wrong choice. Motion is very important when checking tubing for cracks. The tube must move through the coil at a smooth, uniform speed. For best results the tube must also move through the center of the coil.

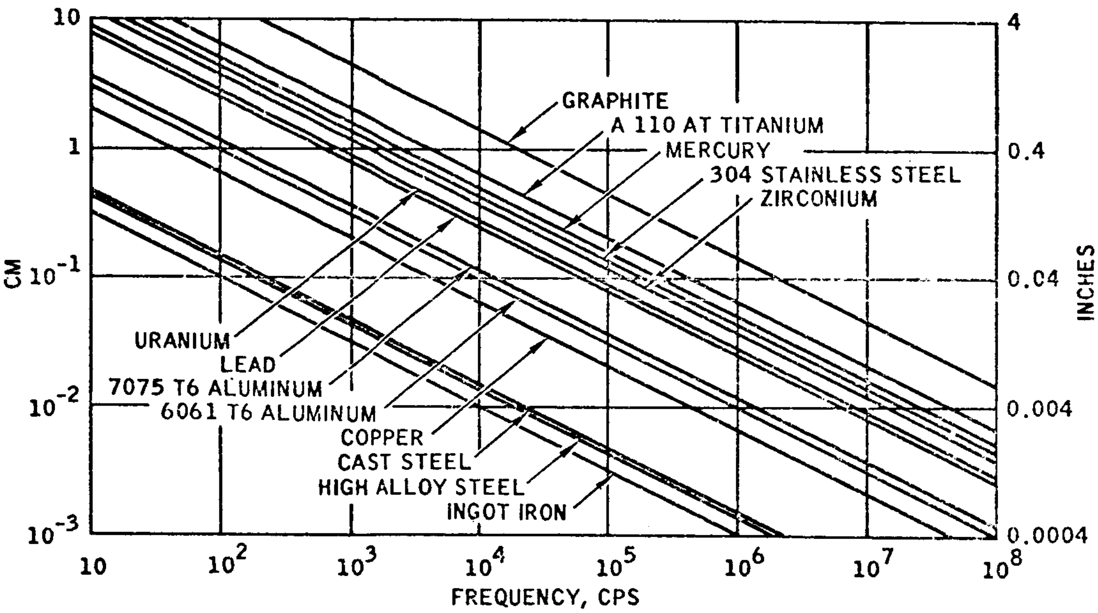
Turn to page 3-53.

Correct! When sorting bolts it is not necessary to have movement.

Depth of Penetration

Another aspect of eddy current testing that cannot be left out of our discussion is that of depth of penetration or choice of frequency. In Volume I, it states that by increasing the test frequency, the depth of penetration decreases. Let's further explain this. Frequency determines the depth of penetration of electromagnetic fields and eddy currents into the metal and therefore the depth of testing. At relatively low frequencies, fields and currents penetrate more deeply. At higher frequencies they are limited to a shallow depth beneath the surface of the specimen and a discontinuity below this shallow surface depth will not be detected.

PENETRATION VS FREQUENCY FOR VARIOUS TYPES OF METALS



Turn to the next page.

From page 3-53

SUMMARY OF CHAPTER 3

First — There are three major divisions of testing systems:

1. Specimen to be tested
2. Testing system
3. Acceptance standards

Second — In the testing system there are four stations:

1. Loading
2. Inspection
3. Accept or reject
4. Unloading

Third — There are two types of coil arrangement:

1. Absolute
2. Differential

Fourth — Conductivity testing is best suited to testing the physical properties (alloy, heat treatment, etc.) of a specimen rather than discontinuities.

Fifth — Discontinuity testing is best suited for the inspection of cracks, holes, dimension, and surface conditions.

Sixth — Thickness testing is best suited for the determination of thickness of coatings, platings, and sheets.

Seventh — A coating is generally thought of as a chemical covering.

Eighth — A plating is generally thought of as a metal covering.

Ninth — A coating is thought of as non-conductive.

Tenth — A plating or sheet is conductive.

Eleventh — Lift-off is the important principle of thickness testing.

Twelfth — Choice of the correct coil for the test is important.

Thirteenth — Magnetic saturation will eliminate the permeability variable in eddy current testing.

From page 3-54

SUMMARY OF CHAPTER 3 (Cont)

<u>Fourteenth</u> Three shapes mentioned for testing are:

1. Cylinders
2. Tubing
3. Sheets

<u>Fifteenth</u> Cylinders are round and solid.

Tubing is round and hollow.

<u>Sixteenth</u> Lift-off is the distance between the coil and the specimen.

<u>Seventeenth</u> Fill factor is the area between the coil and the specimen when using an encircling or inside coil.

<u>Eighteenth</u> Motion (an essential part of most eddy current testing) must be smooth and constant.

<u>Nineteenth</u> The choice of test frequency determines the depth of penetration.

From page 3-55

1. List the three major divisions of a testing system:

   1. S______________ 2. I__________ system 3. A __________ standards

   Hint - These are things you must have. You <u>cannot</u> perform a test without them.

---

6. Coating thickness
   Plating thickness
   Sheet thickness

NON-CONDUCTIVE
NON-CONDUCTIVE

7. Can this arrangement be thickness tested by the use of eddy current?

   Yes ______ No ______

---

12. False

13. The inside surface of a hollow tube could best be checked by an inside coil.

    True ______ False ______

---

18. hollow

19. The distance between the specimen and the surface coil is termed

    ________________ - ________________.

From page 3-56

1. Specimen
   Testing system
   Acceptance standards

2. List the four stations usually required in a testing system:

   Station 1. L________________ Station 3. A__________ or R__________

   Station 2. T________________ Station 4. U________________

7. No

8. A chemical covering on a base metal is called a c________________.

13. True

14. Metal plates are tested with a s________________coil.

19. lift-off

20. The area between the specimen (cylinder) and an encircling coil is called the ____________ factor.

2. Loading, Testing
Accept or Reject
Unloading

3. Variations in the properties of the metal are best detected by discontinuity testing.

True _____ False _____

8. coating

9. A metal covering on a base metal is called a p_______________.

14. surface

15. Magnetic _____________ eliminates the effects of the permeability variable.

20. fill

21. Will relative motion between the specimen and the coil have any effect on the test?

Yes _____ No _____

From page 3-58

3. False

4. Cracks, holes, dimension, inclusions are best detected by discontinuity testing.

True ______ False ______

9. plating

10. A very important principle of thickness testing is lift-off.

True ______ False ______

15. saturation

16. Some of the common shapes that can be tested with eddy current are:

1. C________ 2. T______ 3. S__________

21. Yes

22. When choosing the correct frequency for a test, knowing the desired d_______ of p____________ will aid in making the choice.

4. True

5. By s______________ the test specimen with a strong magnetic field, the permeability effect can be reduced to zero.

10. True

11. Depth of ______________ can be a useful principle in thickness testing.

16. Cylinder
Tubing
Sheet

17. A solid round bar is termed a c________r.

22. depth of penetration

23. Nothing left but the final test. Turn to page 3-62.

From page 3-60

5. saturating

6. The most common uses of thickness testing are:

C________ thickness, P________ thickness, S________ thickness

Return to page 3-56, frame 7.

11. penetration

12. A surface coil would be used to test wire for discontinuities.

True _____ False _____

Return to page 3-56, frame 13.

17. cylinder

18. Tubing is round and h__________.

Return to page 3-56, frame 19.

You shouldn't be here.

From page 3-60

You have just completed the second volume of the programmed instruction course on Eddy Current Testing.

Now you may want to evaluate your knowledge of the material presented in this handbook. A set of self-test questions are included at the back of the book. The answers can be found at the end of the test.

We want to emphasize that the test is for your own evaluation of your knowledge of the subject. If you elect to take the test, be honest with yourself - don't refer to the answers until you have finished. Then you will have a meaningful measure of your knowledge.

Since it is a self evaluation, there is no grade - no passing score. If you find that you have trouble in some part of the test, it is up to you to review the material until you are satisfied that you know it.

Turn or rotate the book 180° and flip to page T-1 at the back of the book.

EDDY CURRENT TESTING - VOLUME II

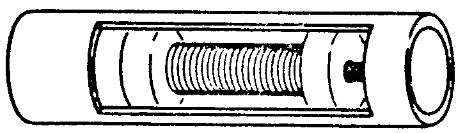
Self-Test

1. List the three most commonly used eddy current test coils.

   a. ________________ c. ________________

   b. ________________

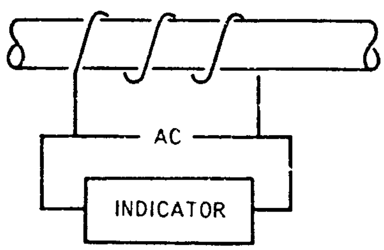
2. The below illustration shows an ____________ coil.



3. The ability to evaluate the entire circumference of a specimen (when the specimen is a bar or tube) lies with the ____________ coil and the __________ coil.

4. The coil that will most accurately pinpoint the exact location of a discontinuity is the __________ coil.

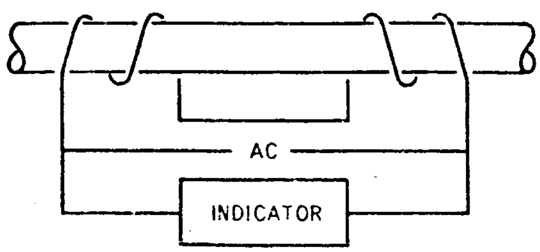
5. Identify the coil arrangement shown below.



Circle one:

a. single coil differential
b. single coil absolute
c. single coil opposed
d. double coil surface

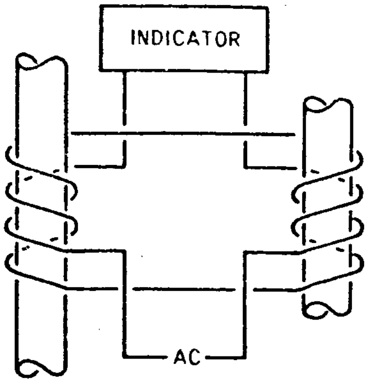
6. Identify the coil arrangement shown below.



Circle one:

a. single coil differential
b. single coil absolute
c. absolute direct
d. external specimen

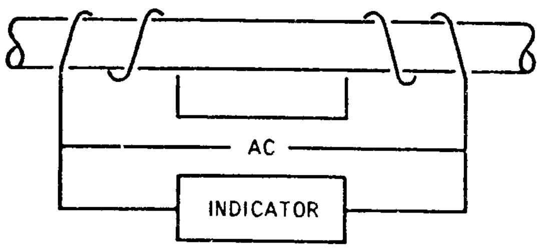
7. Identify the coil arrangement shown below.



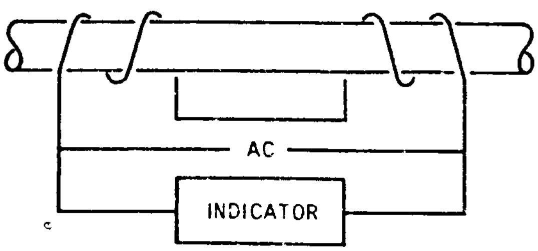
Circle one:

a. single coil absolute
b. single coil differential
c. double coil differential
d. double coil absolute

8. In the illustration below the coils are wound such that their electrical fields will ______________ each other.



9. The illustration below, in which the coils compare one place on a specimen with another place on the same specimen is called the ______________ method.



Circle one:

a. double coil differential
b. single coil absolute
c. self-comparison
d. external reference

10. When using a differential coil arrangement and there is a discontinuity under only one of the coils, will there be an indication?

Yes _____.　　　　No _____.

11. Surface coils must be placed in intimate contact with the base metal to have any eddy currents induced at all.

True ______.　　　　False ______.

12. Another comparison type - differential coil arrangement - using a separate, discontinuity free standard would be called

Circle one:

a. external reference
b. self comparison
c. single coil absolute

13. A change in the specimen size or dimension will not affect the coil impedance or give an indication.

True______. False______.

14. Will an inside coil inspect the entire circumference of the inside surface of a tube at one time?

Yes______. No______.

15. With differential coil arrangement the coils are wound so that they cancel out and give a zero indication.

True ______. False ______.

16. In impedance testing, is it possible to distinguish between cracks in the specimen and changes in the diameter?

Yes______. No______.

17. This statement, "The total sum of the opposition to current flow in an ac circuit", applies to:

a. impedance testing b. reactance testing

18. Which of these testing methods detect and display changes in oscillator frequency?

Circle one:

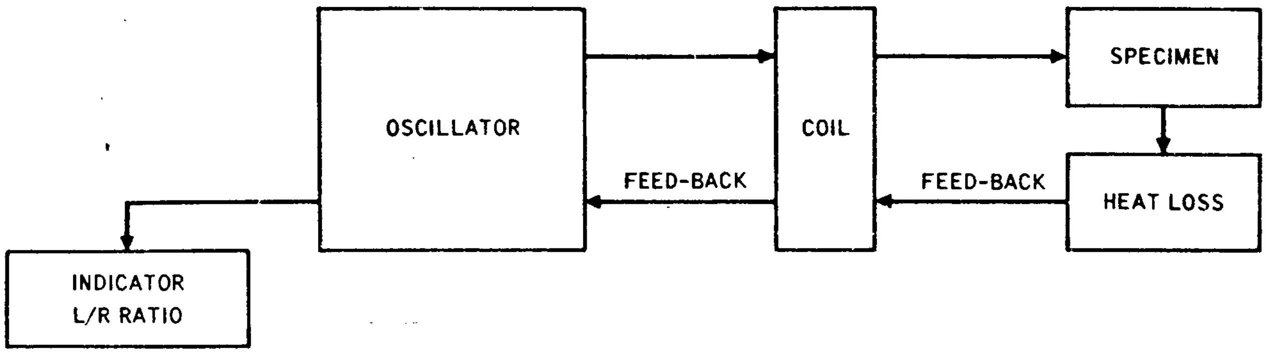
a. impedance
b. reactance
c. feedback-controlled

19. Of the three testing methods listed below, which of them can distinguish between conductivity and dimension? Circle one:

a. impedance testing
b. reactance testing
c. feedback-controlled testing.

20. The __________ - ____________ testing method senses the ratio of induction to resistance and displays this ratio on the indicator.

21. This illustration . . .



is a block diagram of which testing method? Circle one:

a. impedance b. reactance c. feedback-controlled

22. A ____________ _____ ________ (CRT) gives more information about the specimen than a meter.

23. List the three testing methods studied that use a CRT for indications.

1. V____________ P____________
2. E____________
3. L____________ T________ - ________

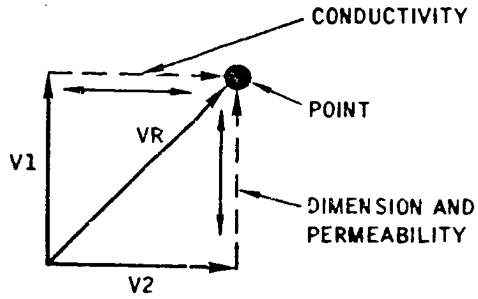
24. The __________________________ equipment is such that the signal from the test coils will always be displayed as a point of light.

25. If a conductivity change will move the point of light horizontally, and a dimension or permeability change will move the point vertically,

What will happen if there is no change at all in the specimen? Circle one:

a. point will not move.
b. point will move to center of screen.
c. point will not appear.

26. With a change in dimension or permeability, which way would the point of light move?



a. horizontally (left and right)   b. vertically (up and down)

27. Will the Vector Point method separate the conductivity from the dimension changes?

Yes______.   No ______.

28. Of the below listed variables, which is the most difficult to separate?

Circle one:

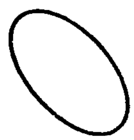
a. conductivity - dimension
b. dimension - permeability
c. permeability - conductivity

29. By adjusting the_________shifter on the CRT, it is possible to move the signal to the right or left of the tube.

30. An _____________is a circle as it appears from an angle other than head on or directly from its side.

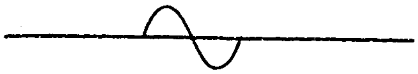
31. The Vector Point method will sometimes display a straight line on the cathode ray tube.

True______.   False______.

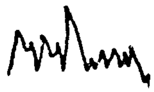
32. 

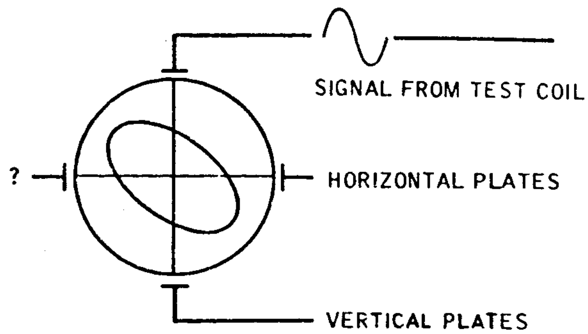
This is the display that appears on the CRT when using the_____________testing method.

33. Which of these signals is sent to the horizontal plates of the CRT in the ellipse method?

a. 

b. 

c. 

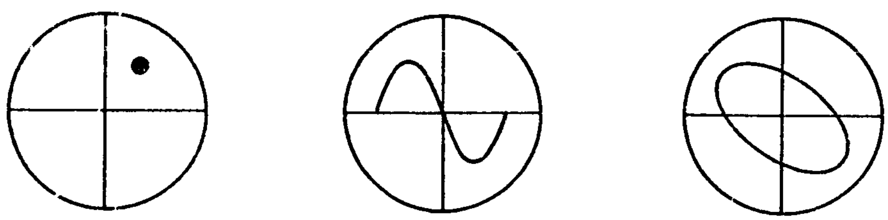


34. The phase s____________serves to position the CRT signal left and right on the tube screen.

35. Will the ellipse method of eddy current testing separate or distinguish between conductivity and dimension?

Yes______.   No______.

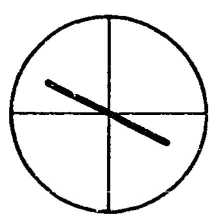
36. Identify each of the following testing methods.



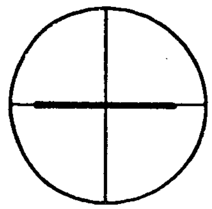
__________   __________   __________

37. In the ellipse testing method this signal on the CRT indicates a . . .

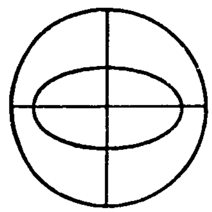
a. dimension change
b. conductivity change



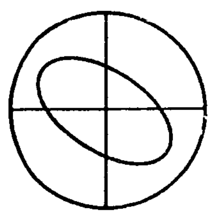
38. In the ellipse testing method, this signal on the CRT indicates __________ change in the specimen.



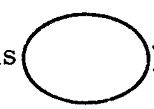
39. In the ellipse testing method this signal on the CRT indicates a __________ change in the specimen.



40. In the ellipse testing method this signal on the CRT indicates both a __________ change and a __________ change.



41. The larger the dimension change, the greater the ____________ of the line on the CRT.

42. When the ellipse opens wider (from this  to this )

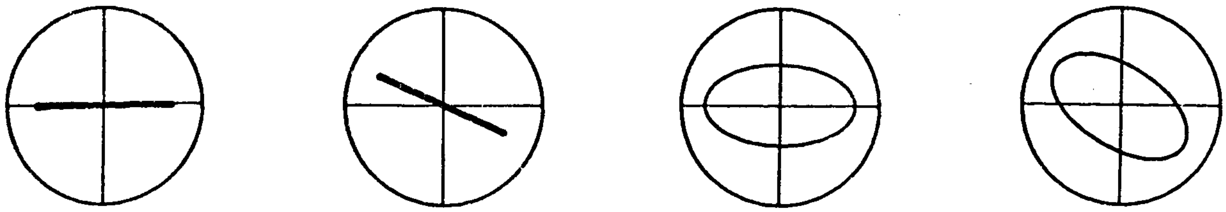
it indicates an increase in the __________ change.

43. A crack, inclusion or a hole, would be sensed as a:

a. dimension change   b. conductivity change

[redacted]

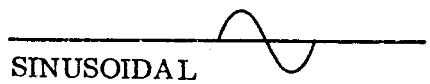
44. Identify the following indication in the ellipse testing method.



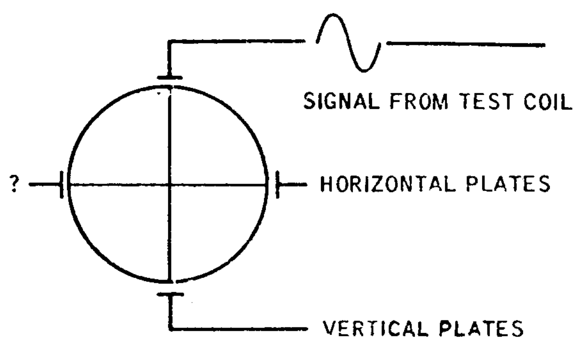
________ ________ ________ ________

a. conductivity change
b. no change
c. impedance change
d. dimension change
e. conductivity and dimension change

45. Which signal is placed on the horizontal plates of the CRT when using the linear time-base method?

a. 
SINUSOIDAL

b. 
SAWTOOTH



46. In the ellipse method and the linear time-base method, the signal from the coils (specimen) is placed on the__________plates.

a. horizontal
b. vertical

47. The X and R____________controls on the linear time-base equipment help to smooth out the signal so that a straight line is obtained on the CRT.

Circle one:

a. balance
b. phase
c. amplifier
d. shifter

48. Which of the controls (Balance/Phase) will shift the signal left and right on the Cathode Ray Tube?____________________

49. The slit technique is used on the CRT with the________________________method.

50. When using the linear time-base method, the signal on the CRT will move ______________(up or down/left or right) if a discontinuity is detected.

51. The waveform will appear to move ______________(up or down/left or right) when using the slit on the CRT.

52. Will the linear time-base equipment separate conductivity from dimension and permeability?

Yes_____. No_____.

53. Which will give the most information about the discontinuity?

a. The cathode ray tube b. The meter

54. A chart recorder is used with which method of eddy current testing:

a. Vector point
b. Ellipse
c. Modulation analysis

55. Is all information that is dislayed on a chart recorder, valuable to the test?

Yes_____.
No _____.

56. ______________ ______________test system acts as a filter to remove unwanted information from the display on the chart recorder.

57. Modulation analysis indicates its results usually on a__________recorder.

58. List three basic requirements for a testing system.

a. S______________
b. T______________ S______________
c. A__________ S______________

59. Complete the following:

Station 1. Loading
Station 2.______________
Station 3.______________ or______________
Station 4. Unloading

60. Conductivity is expressed as a . . . . . . Circle one:

a. time (3 minute)
b. percent (70% IACS)
c. voltage (150 volts)
d. distance (1/8 inch)

61. Variations in the physical properties of a specimen can best be detected by ____________ testing

a. conductivity
b. discontinuity

62. By m____________ s____________ of the test specimen, the permeability effect can be reduced to zero.

63. List the three thickness tests that are studied.

a.________________ b.________________ c.________________

64. The________-________is the distance between the specimen and the test coil when using a surface coil on a specimen.

65. The________ ________is the area between the specimen and the test coil when using an encircling coil or inside coil.

66. A chemical covering on a specimen is termed__________.

67. Paint, varnish, wax, and plastics would be considered as______________.

a. coating
b. plating
c. sheet

68. A metal covering on the specimen, would be considered________________.

a. coating
b. plating
c. sheet

69. Measuring the thickness of a thin layer of copper on the surface of a one inch aluminum plate would be:

a. plating thickness
b. coating thickness
c. sheet thickness

70. Which of the following could not be used in eddy current testing?

a.

CONDUCTIVE
NON-CONDUCTIVE

b.

NON-CONDUCTIVE
NON-CONDUCTIVE

c.

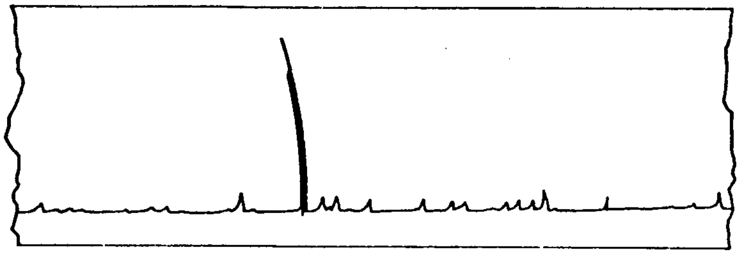
NON-CONDUCTIVE
CONDUCTIVE

71. As the plating thickness increases, the conductivity increases and the depth of penetration____________(increases/decreases).

72. Which chart below shows the results of magnetic saturation?

a.

b.



73. Lift-off is closely related to . . .

a. frequency
b. fill factor
c. time
d. through coil

74. Which one of the following is <u>not</u> an eddy current <u>instrument variable</u>?

a. frequency
b. phase
c. differential
d. modulation

75. A <u>non-conducting</u> material can be <u>tested</u> for discontinuities with eddy currents.

True______. False______.

76. The depth of penetration can be increased by:

a. increasing frequency
b. decreasing frequency
c. increasing lift-off distance

77. With reference to "signal" and "noise", the "signal" refers to:

a. unimportant variables
b. variables of interest
c. phase
d. permeability

78. The ratio of the coil diameter to the specimen diameter is a function of the:

a. fill factor
b. lift-off
c. depth of penetration

ANSWERS FOR SELF-TEST

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	Surface (Probe)	
2.	Inside	1-2
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6.	a. differential	1-14
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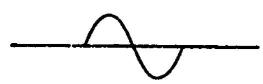
29.	phase	2-29
30.	Ellipse	2-31
31.	False	2-20
32.	Ellipse	2-31
33.	a 	
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35.	Yes	2-39
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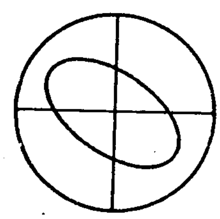
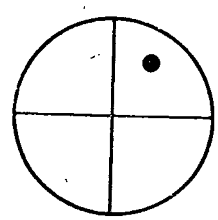
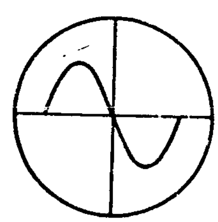
ELLIPSE



VECTOR POINT



LINEAR TIME-BASE



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41.	angie or inclination	2-50
42.	conductivity	2-50
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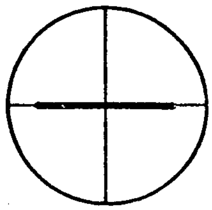
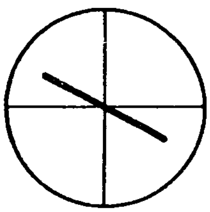
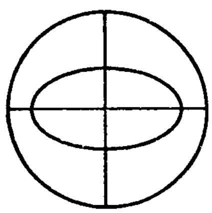
a. NO CHANGE



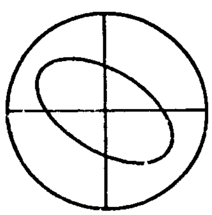
b. DIMENSION CHANGE



c. CONDUCTIVITY CHANGE



d. CONDUCTIVITY AND DIMENSION CHANGE



45. b. SAWTOOTH

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